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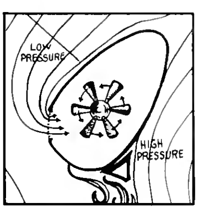

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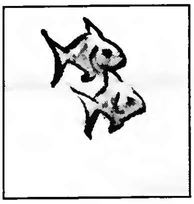

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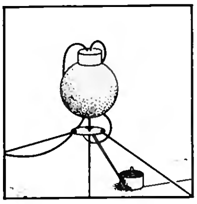

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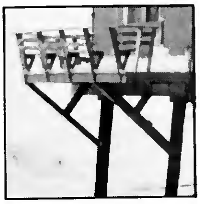

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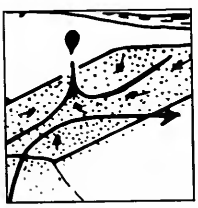

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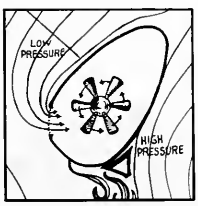

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"We should be thankful. What if oil and water *did* mix!"

Oil Pollution:

A Decade

of Research and Monitoring

by John W. Farrington

Few technological disasters ignite the public's imagination so much as a major oil spill. The site of a broken ship or an out-of-control well is matched with heart-rending visions of struggling seabirds and blackened beaches. Surely, the typical observer speculates, this is one arena in which stricter regulations and enforcement could prevent damage to the environment.

But the problem of oil pollution in the ocean is much more complex than such striking images might lead one to believe. The vast majority of oil pollution comes not from highly visible accidents, but from much more ordinary sources, such as sewer outfalls, ships' bilges, and normal oil tanker operations. Furthermore, oil is an amalgam of thousands of chemicals, each affecting the marine environment and marine organisms in different ways.

The effect of any given chemical is far from certain. Wind, waves, and currents, all of which vary in intensity from location to location, act to disperse the oil. As a result, a given oil spill may be diluted rapidly or may remain concentrated in a small area. Sunlight and microorganisms may modify the composition of the oil. Some oil may dissolve in seawater or become attached to suspended particles of solid matter that later settle to the ocean bottom. Finally, the ultimate effects of oil pollution depend on the uptake of the various petroleum chemicals by fish, crabs, lobsters, and other marine organisms.

Unfortunately, understanding these obstacles to evaluating the effects of oil pollution is of no help in making pressing policy and regulatory decisions. As with decisions to limit the use of pesticides or to stop disposal of sewage sludge at sea, a decision to reduce the input of petroleum to the environment would involve significant costs to society—costs that must be balanced against the detrimental environmental effects of not acting. As a result, such decisions require more quantitative information than is available in many cases. Decision-making on such complex issues relies heavily on periodic, thorough reviews of present knowledge by groups of scientists.

In 1975, the National Research Council (NRC) published just such a thorough review, entitled *Petroleum in the Marine Environment.* It provided guidance for policy, monitoring, and regulatory activities related to oil pollution in the United States and elsewhere. In addition, the report stimulated much research during the last decade. New knowledge resulting from this research, coupled with expanding exploration for and production of oil in several valuable fishing areas, prompted a request from U.S. government agencies for an update of the 1975 report. The urgency of this request was augmented by questions about the long-term impacts of visually spectacular oil spills, such as the *Amoco Cadiz* tanker spill on the coast of France in 1978 and the IXTOC-I oil-well blowout in the Gulf of Mexico in 1979.

The process of updating, begun in 1980, was completed this April with the publication of the 1985 report, entitled *Oil in the Sea: Inputs, Fates, and Effects.* More than 100 scientists contributed to the report [see box page 9]. Despite my attempt to portray their findings accurately, it is inevitable that a summary cannot possibly convey all the details present in the 601 pages of the report.*

In updating the report, two key questions had to be answered. What happens to oil in the marine environment during the course of years and decades? What are the effects of oil on marine

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* Interested readers may obtain a copy of the report for $39.50 from the National Academy Press; 2101 Constitution Avenue, N.W.; Washington, D. C. 20418.

organisms at all levels of complexity, again considering time scales ranging up to decades?

Sources and Characteristics

A major problem in evaluating the fate and effects of petroleum in the ocean is the complexity of the mixture of chemicals we call petroleum. Thousands of compounds are found in most crude oils. During refining, crude oils are processed to yield "fractions" for different uses. These fractions are, in fact, just that—groupings by molecular weight or type of chemicals isolated from crude oil. But even one of these fractions, such as home heating oil or jet fuel, can contain more than 100 chemicals.

The chemicals in petroleum are of many types. Hydrocarbons—compounds made up of only hydrogen and carbon—are the most abundant. Hydrocarbons can be subdivided into alkanes and aromatic hydrocarbons. Alkanes are formed of linear chains of carbon with hydrogen atoms coming off the sides much like the hairs on a caterpillar. Aromatic compounds feature a ring of carbon atoms, and several are used in making polyester, DDT, mothballs, and vanillin (an artificial flavoring used in perfumes and ice cream). Other compounds found in petroleum in smaller quantities include the N, S, O heteroatom compounds, in which nitrogen (N), sulfur (S), or oxygen (O) atoms replace a carbon atom. Sulfur and traces of metals such as vanadium, nickel, and iron also may occur in petroleum.

Unfortunately for those of us who try to examine the effects of petroleum on marine systems, petroleum is not the only source of such compounds. Organisms synthesize alkanes, and simple transformations of other organic compounds can yield small amounts of certain alkanes and aromatic hydrocarbons. Thus, there are normal biological processes already contributing hydrocarbons to the environment. However, petroleum contains more aromatic hydrocarbons and N, S, O, heteroatom compounds than normally are present. This may be particularly significant because aromatic compounds seem to be more harmful to marine organisms than other hydrocarbons. Another complicating factor is that incomplete combustion of fossil fuels (coal, oil, gas) and wood yields aromatic hydrocarbons of the same types as those found in petroleum. The origin of a given aromatic hydrocarbon can be determined only through detailed chemical analyses.

Table 1 presents the best estimates available for sources of petroleum hydrocarbon inputs to the marine environment. There are several very important messages contained in this table, but three important qualifiers need to be emphasized. *First,* these estimates are averaged in time and space. At any given location or any given time interval the relative importance of each source of input can vary substantially. For example, oil-tanker-related inputs will occur where there are oil tankers (Figure 1). *Second,* the estimates have a wide range of uncertainty—more so for some categories than others—because accurate measurements or means of estimation for global inputs are rare. *Third,* the estimates are for total petroleum hydrocarbons; the data base does not permit accurate input estimates for those portions of petroleum, such as the aromatic hydrocarbons, known or suspected to cause adverse biological effects.

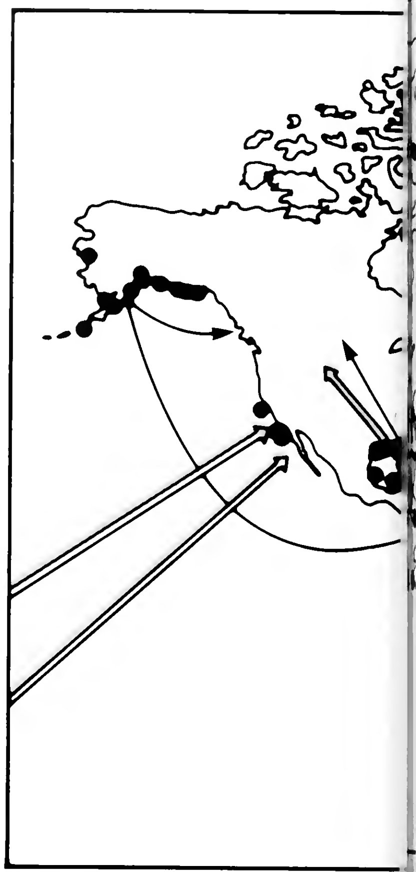
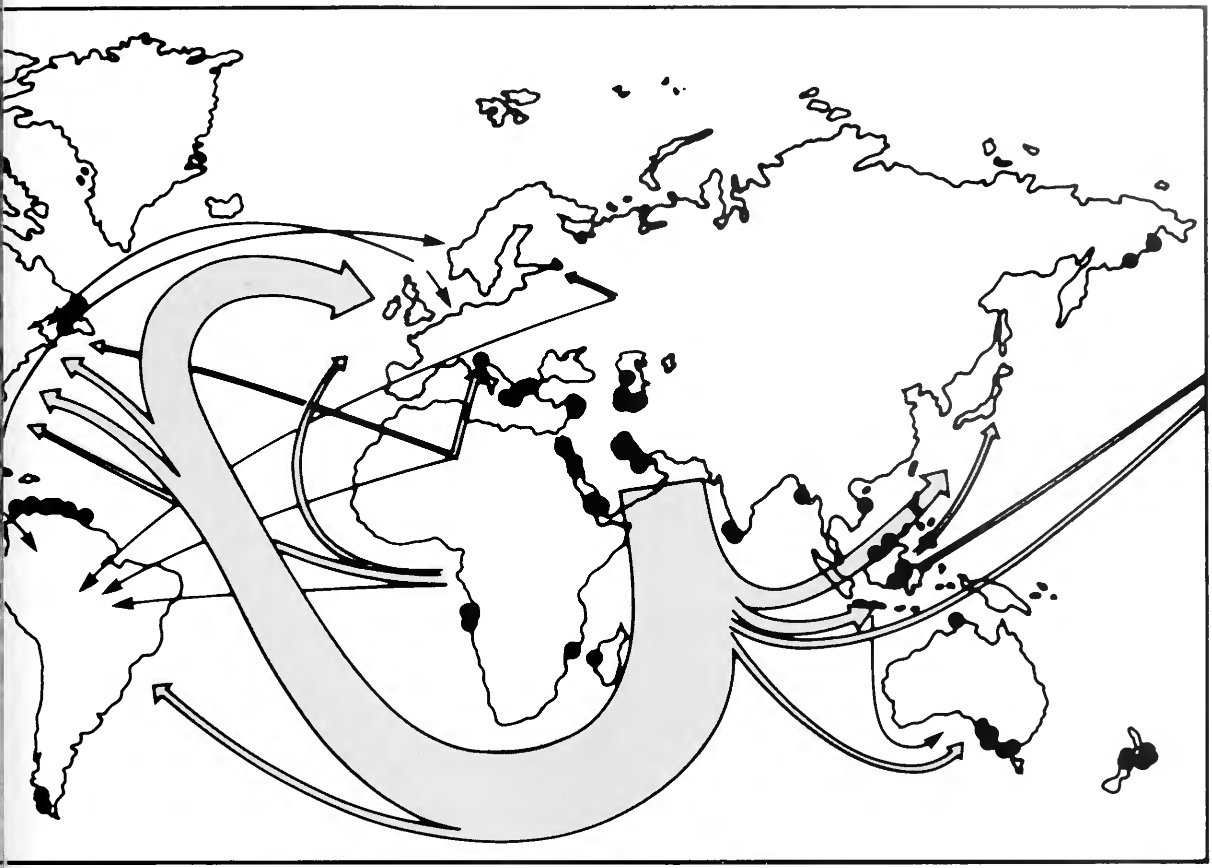


Figure 1. International oil transport routes (arrows) and the location of natural petroleum seeps (dots).

The world's oceans have received inputs of petroleum for a long time—probably for at least 100,000 years. The sources of these inputs are seepage of oil from natural reservoirs near the Earth's surface and erosion of sediments, such as shales, that contain petroleum-like hydrocarbons. Approximately 0.25 million tons of petroleum per year, mostly from seeps, enter the oceans from natural sources (Figure 1). Thus, low levels of petroleum contamination have existed since well before human use of petroleum began. I do not mean that human inputs of petroleum to the ocean are harmless; rather I want to point out that the world's oceans were not pristine with respect to petroleum—especially in seep areas.

The 1985 NRC report also reaffirms two important findings of the 1975 report:

- *Accidental inputs are a small fraction of the total inputs.*
- *Land based sources—industrial effluents, municipal sewer effluents, marine tanker terminal and dry dock operations, and urban*



runoff—account for more than a third of the total input (Table 1).

Table 1. Input of petroleum hydrocarbons into the marine environment in million tons per year.

Source	Probable Range	Best Estimate*
Natural sources		
Marine seeps	**0.02–2.0**	**0.2**
Sediment erosion	**0.005–0.5**	**0.05**
Total natural sources	**0.025–2.5**	**0.25**
Offshore production	**0.04–0.06**	**0.05**
Transportation		
Tanker operations	**0.4–1.5**	**0.7**
Dry-docking	**0.02–0.05**	**0.03**
Marine terminals	**0.01–0.03**	**0.02**
Bilge and fuel oils	**0.2–0.6**	**0.3**
Tanker accidents	**0.3–0.4**	**0.4**
Nontanker accidents	**0.02–0.04**	**0.02**
Total transportation	**0.95–2.62**	**1.47**
Atmosphere	**0.05–0.5**	**0.3**
Municipal and industrial wastes and runoff		
Municipal wastes	**0.4–1.5**	**0.7**
Refineries	**0.06–0.6**	**0.1**
Nonrefining industrial wastes	**0.1–0.3**	**0.2**
Urban runoff	**0.01–0.2**	**0.12**
River runoff	**0.01–0.5**	**0.04**
Ocean dumping	**0.005–0.02**	**0.02**
Total wastes and runoff	**0.585–3.12**	**1.18**
TOTAL	**1.7–8.8**	**3.2**

The chronic dribbling of petroleum from sloppy use by modern society is responsible for a large fraction of the input to the world's oceans. This fact usually is greeted with surprise by a general public that associates oil pollution with tanker spills and offshore oil-well blowouts (Figure 2). Accidental oil spills are important in the local areas or regions of the ocean where they occur, but are a small percentage of total inputs over the course of several years.

A major source of uncertainty about the sources of contamination is petroleum or petroleum-like hydrocarbon input from incomplete combustion of fossil fuels and wood. These compounds may be transported to the ocean by wind. Little more can be said about the relative magnitude of such inputs than was said in 1975––that this is one of the major sources of hydrocarbon inputs to the ocean. Very little progress has been made since 1975 in obtaining actual measurements of fossil fuel compounds in the atmosphere over the ocean or in rain collected at sea.

*** The total best estimate, 3.2 million tons per year, is a sum of the individual best estimates. A value of 0.3 was used for the atmospheric inputs to obtain the total, although the author realizes that this best estimate is only a center point between the range limits and cannot be supported rigorously by data and calculations.**
Source: 1985 NRC report.

Figure 2. The IXTOC-I oil-well blowout. To the left of the well, flames, barely visible, rise some 30 meters. The larger ship in the background is more than 250 meters long.

Another problem is the existence of extensive geographical gaps in data, especially for the southern hemisphere. This requires estimating global petroleum inputs by using data on inputs from a few countries and extrapolating these data to other countries where patterns of petroleum use and release to the environment may be quite different.

Fate of Petroleum Inputs

Once petroleum enters the oceans, it begins to be acted on by a wide variety of processes (Figure 3). One of the first is contact with sea water. The old adage "oil and water do not mix" is true for the bulk of accidentally spilled oil—for short periods of time. But over a period of hours to months some mixing will occur. Furthermore, the adage does not apply to petroleum compounds entering the ocean already dissolved in water or widely dispersed in another medium, such as urban runoff, waste effluents, or the atmosphere. Some compounds in petroleum, while not as soluble as other organic chemicals such as sugar, are somewhat soluble in seawater. Other compounds enter the water column as dispersed droplets and water-in-oil emulsions (resembling a freshly shaken bottle of salad dressing) mixed together by wind, waves, and currents. The more volatile portions of petroleum are generally lost to the atmosphere by evaporation from slicks or, if they entered the water via a subsurface effluent, by sea-air gas exchange.

Some oil becomes attached to solid particles suspended in the water through the twin processes of adsorption (clinging to the surface of a solid) and absorption (being soaked up by a solid, as by a sponge). These particles may later sink to the bottom, carrying the oil with them, resulting in incorporation of petroleum compounds into sediments. Oil also may reach sediments in shallow waters by turbulent mixing throughout the water column down to the sediment-water boundary. This is an important phenomenon because once incorporated into sediments the compounds may have a long-term impact on bottom-dwelling organisms that are key components of coastal ecosystems.

An impressive amount of new knowledge about bacterial degradation of oil in the oceans has been obtained during the last decade. Numerous strains of bacteria have been isolated that are capable of metabolizing one or more classes of petroleum compounds. Field studies have demonstrated quite clearly that these bacteria are present at spill sites and chronic release sites in much greater numbers than at oil-free sites. These studies also have demonstrated that the mere presence of oil-metabolizing bacteria is not sufficient to guarantee that oil compounds will be destroyed. Sufficient nutrients and oxygen must be present—and oil, nutrients, and oxygen must be mixed together in the correct manner—to attain significant metabolism. If good mixtures are achieved, bacterial metabolism can be quite rapid for certain classes of compounds. If conditions for growth are poor, rates of metabolism are significantly slower. In addition, the type of oil involved has a major effect on microbial degradation. Although 90 percent of some crude oils may be biodegradable, as little as 11 percent of others may be so broken down.

Since the 1975 report was written, marine photochemistry has emerged as a subdiscipline of marine chemistry. Concomitantly, photochemical processes acting on petroleum in the oceans are now being investigated in more detail. The pioneering work of a few scientists in the mid- to late 1970s alerted researchers to the importance of these reactions. For example, some experiments have shown that certain oils subjected to photochemical alteration are more toxic to some marine organisms than the unaltered oil.

In such bacterial and photochemical processes, oxygen is added to hydrocarbon molecules. This changes them from electrically neutral compounds to more polar compounds, with positively and negatively charged sections. As a result, they are able to mix more readily with the water molecules, which are also polar. The presence of these polar compounds in spilled oil may promote or assist in the formation of water-in-oil emulsions, which greatly alter the fate and effects of spilled oil. The water-in-oil emulsions are often referred to as "mousse" because they resemble chocolate mousse. In some cases, the mousse accumulates in large patches at oil spill sites. Studies at the IXTOC-I oil spill demonstrated that mousse "rafts" could float across the Gulf of Mexico and deliver relatively fresh oil (that is, oil not extensively altered by evaporation, dissolution, or microbial metabolism) to shorelines a thousand kilometers from the spill.

A wide variety of marine organisms will take up petroleum compounds from water, sediments, or food. Some of these organisms—such as bivalve molluscs, worms, crabs, lobsters, and fish—can release petroleum compounds back to the environment after the petroleum contamination is reduced or removed. The rate of uptake and the final concentration attained in a given organism's tissues depend on the chemistry of the compounds,

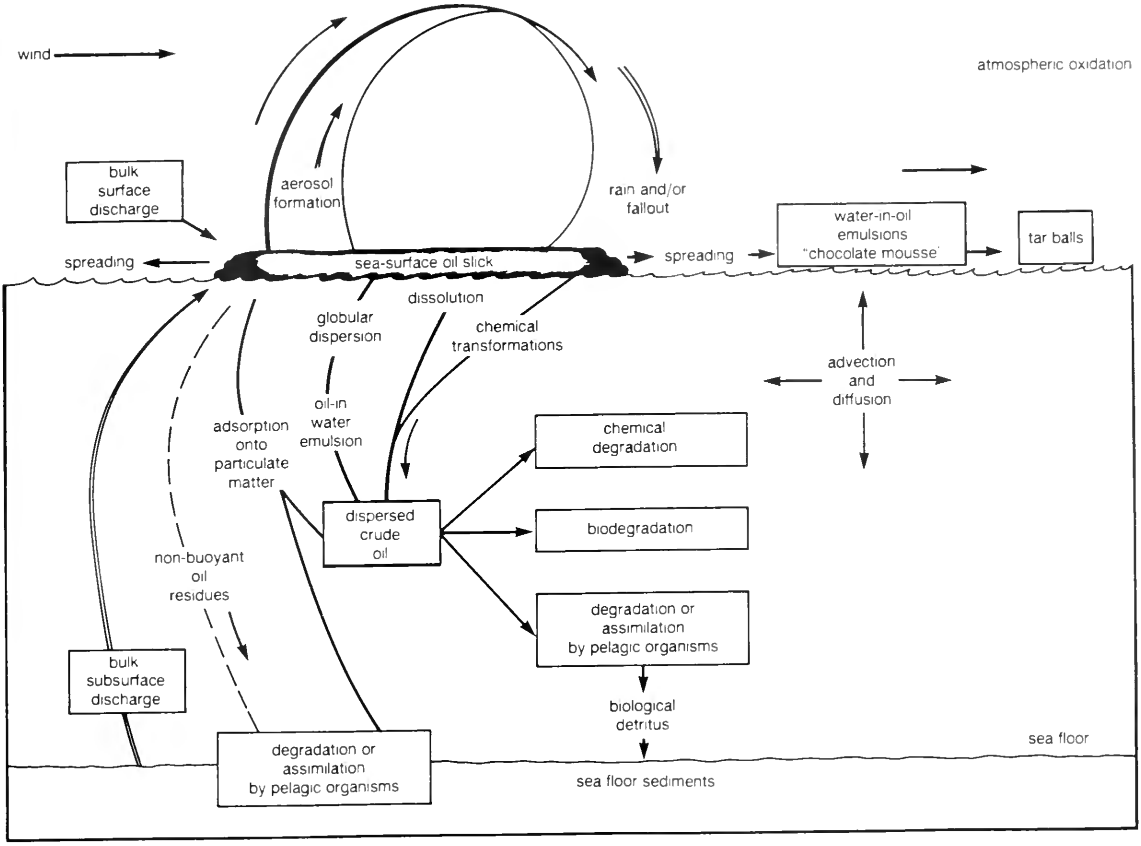


Figure 3. Some of the processes affecting oil once it enters the marine environment.

the form of exposure, and the concentration and duration of exposure. Release back to the environment is dependent on similar parameters. Shellfish transplanted from contaminated urban harbor areas to relatively clean waters require at least several months to reduce concentrations of petroleum in their tissues to levels found in the same species residing naturally in the clean areas.

In addition to releasing compounds, several species of fish, crustaceans, birds, marine mammals, and worms can metabolize aromatic hydrocarbons and excrete the resulting products. Thus, these marine organisms have a means of reducing their burden of toxic compounds. But the metabolism process can be a two-edged sword. Metabolites of some higher molecular weight aromatic hydrocarbons may be mutagenic or carcinogenic. The extent to which this is a problem for the organism that produces them is being investigated.

Overall, despite impressive progress, it is not yet possible to measure the rates of the major processes acting on petroleum inputs so as to make a mathematical model for the fate of petroleum from a given source. Only for some well-studied oil spills, such as the *Amoco Cadiz* spill (Table 2), is the fate of the bulk of the oil known.

Petroleum Pollution Today

Scientists researching ocean pollution are often asked "How badly polluted are the oceans with petroleum?" It is a difficult question to answer. Most data on the subject come from coastal areas. There are, however, three types of observations available from the open ocean—slicks on the surface recorded by ships of opportunity, floating tar in surface waters, and rough measurements of dissolved or dispersed hydrocarbons. Since natural slicks from organic matter released by plankton are not differentiated from petroleum slicks by the seamen who observe them, and since the

Table 2. Mass balance accounting of oil spilled by the tanker *Amoco Cadiz*.

	Tons	Percentage
Total Spilled	223,000	
Incorporated into subtidal sediments	18,000	8
Onshore (beaches, marshes, rocky areas)	62,000	28
In or on Water	30,000	13.5
Biodegraded (mainly by bacteria)	10,000	4.5
Evaporated	67,000	30
Unaccounted for	46,000	20.5

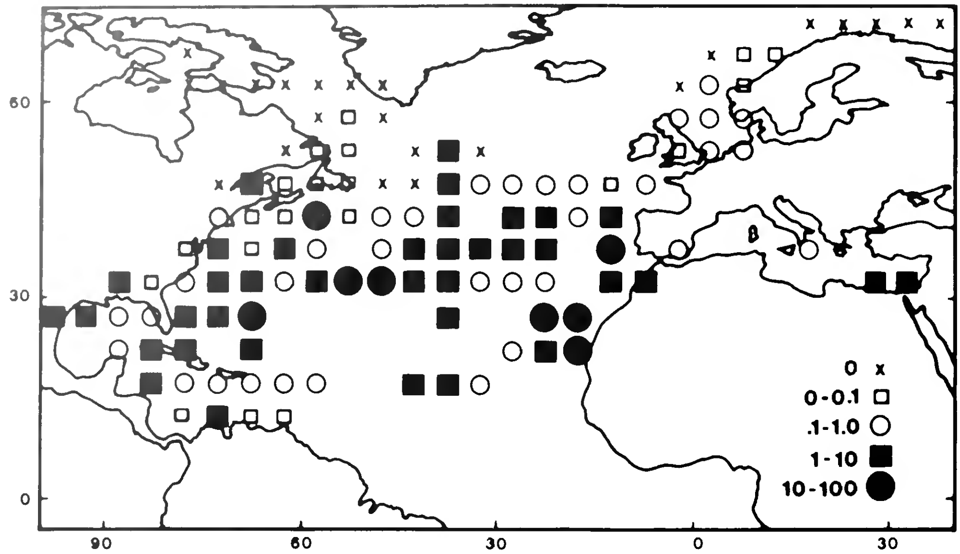


Figure 4. Concentrations of tar balls (in milligrams per square meter) for the North Atlantic. The zero data points indicate that an area was sampled but no tar found.

observations are subjective, not much can be gleaned from the slick observations except that large portions of the world's oceans are free of readily discernible petroleum slicks.

Floating tar is the residue remaining after oil has been acted on by the various processes described previously. This tar comes ashore in many places in the world, and becomes a nuisance to recreational boaters and swimmers. I still possess a bottle of "Tar Away" cleanser sold to bathers on Bermuda in the mid-1970s. Higher concentrations of floating tar are associated with shipping routes, seep areas, and mid-ocean gyres*, such as the Sargasso Sea (Figure 4).

It is possible that the introduction of new, more efficient oil tankers and new procedures for reducing oil inputs from ballast operations at sea have prevented increases in floating tar residues despite increased oil transport at sea. Overall, there is no statistically significant evidence of increase or decrease in levels of floating tar for the ocean as a whole, but this may be due to insufficient data rather than to constant levels of floating tar.

Concentrations of dissolved or dispersed hydrocarbons in open ocean waters have been measured by the most discriminating techniques for only a few samples. Many more samples have been analyzed by less discriminating survey techniques. More of the better-type measurements have been made in coastal waters. In general, concentrations in the open ocean appear to be in the range of 0.1 to 100 parts per billion. The higher concentrations are usually associated with urban harbor areas or areas near other probable inputs. Of course, higher concentrations of dissolved or dispersed oil have been reported in the immediate vicinity of oil spill sites. For example, near the IXTOC-I oil-well blowout concentrations of 500 to 10,000 parts per billion were measured. The majority of the oil, however, was not in dissolved form but present as dispersed droplets of oil. As the oil was transported away from the well site by currents, much of it rose to the surface, and the concentration of that remaining mixed with the water was reduced by dilution as cleaner water mixed with the oil-polluted water.

Marine sediments also may be used as a rough indicator of oil contamination. Measurements of petroleum hydrocarbons in sediments have revealed the not too surprising fact that higher concentrations are found near sources of input. The rate at which concentrations decrease with increasing distance from the source of pollution depends on the type of input and the physical characteristics of the area in question.

Effects of Oil

Oil in the oceans has a number of undesirable effects. There is the obvious aesthetic effect associated with spilled oil and floating tar. This translates into an economic impact in tourist and recreational industries. Fouled fishing gear is also a problem with some types of oil spills. Some petroleum compounds also impart an offensive taint or taste to seafood, under certain conditions rendering the seafood unmarketable. Not all people agree. I have dined with a scientist who claimed, with a straight face, that some U.S. Gulf Coast oysters had a better taste because of oil contamination.

The main concerns and controversies surrounding the effects of petroleum focus on two

* Mid-ocean gyres are enormous, generally tranquil eddies in the middle of the ocean.

Iterations on a Slick Theme

The 1975 National Research Council (NRC) report, Petroleum in the Marine Environment, has proven to be an extremely important document. It has been used as a primary source by individuals and groups ranging from scientific investigators to concerned laymen. However, in mid-1980, it became clear that an update of the 1975 report was necessary. Much of the published material used as a basis for the earlier report predates a workshop held in 1973 that provided most of the background for the 1975 report. Since then, significant new data and information have been published. Thus, the U.S. Coast Guard requested that the Ocean Sciences Board (OSB)—now the Board on Ocean Science and Policy—undertake a new examination of this subject. The OSB appointed a steering committee consisting of cochairpersons Gordon A. Riley, Halifax, Nova Scotia, and William M. Sackett, University of South Florida, along with Rita R. Colwell, University of Maryland; John W. Farrington, Woods Hole Oceanographic Institution; C. Bruce Koons, Exxon Production Research Company; and John H. Vandermeulen, Bedford Institute of Oceanography. Later, the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, the Bureau of Land Management (now the Minerals Management Service), Mobil, Exxon, and the Andrew W. Mellon Foundation joined the U.S. Coast Guard in providing financial support for the project.

The steering committee took the following major steps:

1. A public meeting was held on November 13, 1980, at which representatives from oil industry, university, government, and environmental groups were invited to make presentations on important topics for consideration by the steering committee.

2. In February 1981, 46 expert contributors were invited to prepare summary papers on all aspects of petroleum in the oceans. These were reviewed and commented on by other experts selected by the steering committee.

3. An international workshop was held November 9–13, 1981, at which contributors, reviewers, and other invited scientists came together to discuss the main issues brought out from the previous two steps and to make recommendations concerning future research needs. Approximately 90 of the participants came from U.S. university, governmental, and industrial organizations. Another 22 came from Canada, the United Kingdom, France, Germany, Norway, Israel, and Sweden, providing a strong expert background and a wide range of institutional and foreign governmental expertise to this new report.

4. In February 1982 the steering committee began the task of preparing the new report, based on the input, ideas, and comments obtained by the previous steps. The writing process involved several review steps. Drafts from these iterations were carefully reviewed at several meetings of the entire steering committee. The review process was completed in November 1984.

From the 1985 NRC Report

general issues: human health and effects on valuable living resources. These were major concerns for the 1975 NRC report, but the information available to address them was inadequate to resolve many of the c6ntroversies—particularly the issues of duration of adverse biological effects at oil spill sites and effects of chronic inputs of petroleum compounds in sewage effluents, releases from production platforms, and dredge spoils. These issues have been more thoroughly addressed in the 1985 report.

The concerns in the area of human health focus on petroleum-contaminated seafood. There are several chemicals in petroleum, particularly certain polynuclear aromatic hydrocarbons,* which are known or suspected of being mutagens or carcinogens when taken up and metabolized by humans. Evaluating the seriousness of this problem is hindered by the input to the environment of the same or similar compounds from other activities. Such compounds may enter the environment as soot from the combustion of fossil fuels or leakage from wood pilings impregnated with creosote. Foods other than seafood also may be so contaminated. Other routes of human exposure to such compounds also exist (Table 3).

This discussion does not indicate that the NRC advocates continued inputs of such large aromatic hydrocarbons into the environment, but rather that the problem of such inputs from petroleum should be considered within the perspective of other sources.

To avoid any misunderstandings, I quote directly from the NRC report (p. 482):

> *Thus, at present there is no demonstrated relationship that chronic exposures through eating petroleum-derived [polynuclear aromatic hydrocarbon] contaminated seafood are related to the incidence of cancer or other diseases in humans.*

* Polynuclear aromatic hydrocarbons contain two or more aromatic rings that share at least two carbon atoms.

Table 3. Estimated human exposure to benzo(a)pyrene [B(a)P] through respiratory and gastrointestinal intake.

Source	Daily Consumption	Estimated Annual Intake of B(a)P (micrograms)
Respiratory intake[a]		
Air		0.05–500
Cigarette smoking	20 cigarettes	15–900
Gastrointestinal intake		
Drinking water	2.5 liters	6–70
Food		
Normal diet	1.5 kilograms[b]	250–500
Smoked food diet	1.5 kilograms[c]	550–3000
Potential seafood contribution	100 grams[d]	36.5–1825
Contaminated seafood burden	24–48 grams	263–920

[a] Respiratory intake is assumed to be 5,000 cubic meters per person per year.
[b] For 0.5 micrograms B(a)P per kilogram of food.
[c] Assumed to be contaminated with 1 to 5 micrograms B(a)P per kilogram.
[d] Assumed B(a)P levels from 1 to 50 micrograms per kilogram.

Corrected for error from Table 5-17 of 1985 NRC report.

Exceptions to these conclusions may arise in localized areas, as in the case of isolated fishing villages where seafood constitutes a major portion of the animal diet. No data are available, however, for these cases.

With respect to effects of oil spills on valuable living resources, by the time of the 1975 NRC report there was a consensus that the fate and effects of spilled oil varied enormously depending on such factors as the composition of the oil, temperature, wind, waves, currents, type of ecosystem, and the clean-up measures used to "minimize" the impact of the oil. For example, bulldozing oil-contaminated sediments out of a marsh could have as much, if not more, impact on the long-term viability of the marsh ecosystem as the oil. Fortunately only a few harsh lessons were needed to illustrate that certain "cures" for cleaning up spilled oil were worse than, or as bad as, the "disease."

Studies of accidental oil spills and their effects have provided important general information about what types of environments are most susceptible to damage from spilled oil. Several stretches of coast in areas likely to experience accidental oil spills are now classified as to susceptibility. Low-energy coastal environments (such as intertidal mud flats, marshes, and subtidal areas) appear to be particularly vulnerable to impacts of oil. In these environments, remnants of spilled oil can persist for up to a decade. This is important information for on-scene clean up directors (usually U.S. Coast Guard personnel in the United States) who must decide how best to deploy protective booms and oil clean-up measures as a spill approaches or occurs in a coastal area. Fortunately, oil slick trajectory forecasting has improved; through the use of such information it is possible to minimize the environmental impact of accidental oil spills.

There are substantial regional differences in environmental response to oil pollution. Most research on, and monitoring and assessment of, oil pollution has occurred in northern temperate zones. During the last few years research in polar (Arctic) regions has begun to fill the gap for that climatic regime. Nevertheless, the potential impact of oil inputs on polar ecosystems can be estimated with even less confidence than the uncertain estimates for ecosystems effects in temperate regions.

The Report's Conclusions

In summarizing the effects of oil inputs on the environment, the 1985 NRC report offered a mix of cautious optimism and gaps in scientific knowledge. For example, it pointed out that "where oil has had an effect, subsequent monitoring has shown biological recovery taking place." Furthermore, the report noted that "most living organisms can co-exist with hydrocarbons when concentrations are very low (less than 0.1 [milligrams per liter]) and when the oil is weathered." On the other hand, although it notes that there is little evidence of reduction of commercially important fish stocks by oil pollution, the report emphasized that "present census techniques remain too crude to provide clear knowledge of standing fish stocks, while natural variabilities in the stocks probably mask such impact from petroleum as may exist." Furthermore, the report pointed out a major scientific problem: "The fragmented evidence on the effects of petroleum on some larval fish and fish eggs from a few laboratory and field studies indicates that [adverse] impact is possible, although it has not been rigorously examined. This inability to transfer information obtained from laboratory studies to field conditions has been an intractable problem throughout this report."

Such gaps between laboratory knowledge and field data are evident throughout the conclusion of the report. For example, in examining the carcinogenic and mutagenic potential of petroleum, the report stated that "some petroleum compounds are carcinogens and/or mutagens and can bind to nucleic acids. Metabolic products of petroleum degradation also can be potentially hazardous. However, the data are not available to indicate that such a hazard has occurred in populations [of marine organisms] in affected environments."

Finally, the report expressed great concern about the impacts of oil pollution in coastal and tropical waters. "The greatest impact due to oiling clearly occurs in coastal areas, especially those with shallow water, and in areas where local current systems tend to contain . . . the contaminant. Of special concern are situations of local chronic oiling where there is low level [less than 1 part per million] but continuous exposure, as in waters near industrialized or heavily populated coastal regions. There is a clear need to continue research on these local situations, not only because of the intrinsic toxicity of petroleum, but also because of its poorly understood but suspected synergistic impact with other contaminants."

With respect to tropical areas, the report

Between the Lab and the Ocean: The Role of Mesocosms

In their efforts to determine the effects of oil on the marine environment, scientists have recently turned to a new tool—the mesocosm. Mesocosms are enclosed tanks large enough to incorporate several interacting segments of marine ecosystems. They are helping to fill a crucial gap in scientific knowledge, providing a bridge between the laboratory and the real world.

There is a widespread assumption that oil pollution is extremely harmful to marine organisms. Indeed, laboratory experiments on many different species have shown a wide range of effects, both lethal and sublethal, from exposure to petroleum. In such experiments, effects have been documented at all physiological levels—from individual cells to the whole organism. The problem lies in extrapolating from particular laboratory experiments to the wide range of conditions found in the field.

The types and intensity of effects produced by petroleum and the concentrations at which such effects occur vary widely from species to species. Most laboratory studies have been conducted at much higher concentrations than are found at oil spill sites or chronic input sites, and cannot be strictly extrapolated to lower concentrations.

Field studies do not necessarily clarify the situation. Studies at major sources of chronic inputs (such as urban harbors) often face the problem of distinguishing between petroleum hydrocarbon effects; effects from other pollutants, such as chlorinated pesticides, industrial petrochemicals (PCBs and their relatives), and trace metals; viral and bacterial diseases; reduced oxygen in the water; and the combined effects of all of such stresses. The combined effect may be much greater than the effects of the individual components—a phenomenon referred to as synergism. It also is possible that some pollutants reduce or cancel effects of other pollutants—a phenomenon referred to as antagonism.

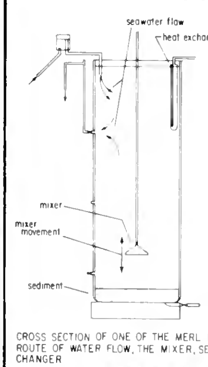
Field studies of accidental oil spills are difficult because of the lack of predictability and the subsequent mad dash to gain valuable initial information. Good marine biologists do not sit around waiting for an oil spill. Furthermore, properly conducted studies of the biological effects of large oil spills are enormously complicated, time consuming, and expensive efforts.

Frustrations with unravelling the complicated interactions in the field have caused researchers to turn to mesocosm experiments. One such experiment, at the Marine Ecosystems Research Laboratory (MERL) at the University of Rhode Island, consists of tanks approximately 2 meters in diameter, 5.5 meters tall, and containing about 13 cubic meters of water, as well as 30 centimeters of sediment along the bottom. The sediments contain typical organisms from the sediments of Narragansett Bay, and the water contains planktonic organisms typical of Bay waters. Simultaneous operation of several mesocosms allows comparison of controls to experimental tanks in which oil is added.

The results from mesocosm experiments demonstrate quite clearly that concentrations of petroleum present around urban harbors, spill sites, and other input sources can alter interactions between organisms in coastal marine ecosystems. Extrapolation of these results to long time periods in entire ecosystems is not possible within the strictures of science and our present knowledge. But the fact that low concentrations did show the adverse impacts in the mesocosms gives us cause for concern. In particular, because they depended on interacting effects among several species, some effects could not be predicted from laboratory toxicity studies on individual species. Further mesocosm studies are in progress and should provide additional insights.

—JWF

MERL MICROCOSM TANK



TANKS	
INTERIOR DIAMETER	1 83 m
INTERIOR HEIGHT	5 49 m
WATER	
DEPTH	5 00 m
AREA	2 63 m^2
VOLUME	13 10 m^3
MASS	13 40 tons
SEDIMENT	
AREA	2 52 m^2
DEPTH	0 30 m
VOLUME	0 76 m^3
MASS (wet)	1 10 tons
(dry)	0 57 tons

CROSS SECTION OF ONE OF THE MERL MICROCOSM TANKS, SHOWING THE ROUTE OF WATER FLOW, THE MIXER, SEDIMENT CONTAINER & HEAT EXCHANGER

stressed the potential impact of oil on mangrove systems and coral reefs. "These represent a major part of the coastline in tropical and subtropical regions and are highly significant in terms of fisheries and other resources. They have unique physical and biological characteristics that make them highly vulnerable to the effect of oiling. Unfortunately, the research effort on these ecosystems has been confined to comparatively few studies."

Personal Comments

There is a strong need for further research on oil in the marine environment, to allow intelligent political, social, and economic choices. Several of the questions regarding oil pollution asked in the late 1960s and early 1970s have been answered by research conducted during the last decade. We now know that biological effects from oil spills do not last more than a decade or two; but such effects can last as long as a decade, not always the year or two that some predicted. Furthermore, areas of the coast can be classified as to degree of susceptibility to long-term effects and plans made to protect these areas during spills. The technology of oil-spill containment and clean up is progressing. Thus, there is the probability that technology coupled with knowledge of oil spill behavior may be used to further minimize adverse impacts of accidental oil spills.

Progress in understanding the toxicity of petroleum to marine organisms has been excellent. The fractions and in some cases specific compounds that are responsible for most of the immediate toxicity in several oils have been identified through the coupling of advanced analytical chemistry techniques with biological effects studies. A concern identified in the 1985 NRC report is that such toxic compounds make up a larger portion of oils derived from shale and coal (synfuels) than of petroleum currently in use. Attention should be given to these environmental concerns early in any planning for a substantial switch to synfuel usage.

The increased knowledge about the uptake and release of compounds and metabolism by marine organisms has yet to be adequately linked with knowledge of sources of inputs. We cannot assume that all sources of input have equal potential for biological uptake. For example, atmospheric inputs of polynuclear aromatic hydrocarbons may not be readily available for biological uptake because of strong binding to atmospheric particulate matter. In contrast, oil entering the marine environment dissolved or dispersed in urban runoff may be readily available. Thus, the physical form of the inputs could control uptake and toxicity. This is an important problem that should be researched prior to taking regulatory and management action to reduce inputs from a given source simply because of the volume of inputs from that source.

Concerns with long-term impacts of petroleum on ecosystems and on fish and shellfish resources cannot be separated from two important factors. *First,* much of the chronic input in continental shelf and coastal waters occurs in areas where inputs of other chemical contaminants and bacteria and viruses also occur. Separating effects of the various inputs or understanding the effects of the combinations are research challenges made more difficult by the *second* factor: knowledge of short-term (years) and long-term (decades) natural fluctuations in populations of organisms is incomplete. Major progress in understanding the effects of chronic petroleum inputs will depend on a better understanding of natural population fluctuations.

The major problem with undertaking these research efforts is ensuring funding. Even once agreement is reached as to which federal agency has the responsibility for such research, a long-term program commitment is still needed. This is a difficult task in science research leadership and management because the duration of the program must be longer than the terms of those elected and appointed to political office. Furthermore, if we are to obtain substance rather than rhetoric, the level of funding must be significant.

One of the most important features of the 1985 NRC report was its emphasis on the dirth of knowledge about oil pollution in tropical areas. Rapid development is proceeding in coastal areas of many developing countries, many of which are in tropical and subtropical areas. Such development often includes offshore production of oil and gas, build up of refining and petrochemical industries, and urbanization in coastal areas. Although some lessons can be translated from oil-pollution research in temperate climates and developed countries, it would be a serious mistake to proceed with development in subtropical and tropical areas without increased research and monitoring efforts.

In summary, research and monitoring focused on oil pollution has shown that the worst fears of the late 1960s and early 1970s have not been realized. Large areas of the world's oceans have not been killed by oil pollution. That these predictions were wrong is in part a function of increased understanding of how the marine environment copes with oil inputs. In part, it may be attributable to reductions in inputs of certain types of oil, such as oil from tanker ballasting operations and in effluent releases from offshore platforms. On the other hand, we cannot be complacent. The effects of many compounds and fractions of petroleum on a myriad of biological processes in the marine environment are not known.

Oil pollution is one of several natural and man-made stresses affecting marine ecosystems. The 1985 NRC report has assessed current knowledge and made recommendations for further research. The next step is to incorporate the report's conclusions and recommendations into an overall strategy for marine environmental quality protection that assesses the relative importance of oil pollution vis-à-vis other types of pollution.

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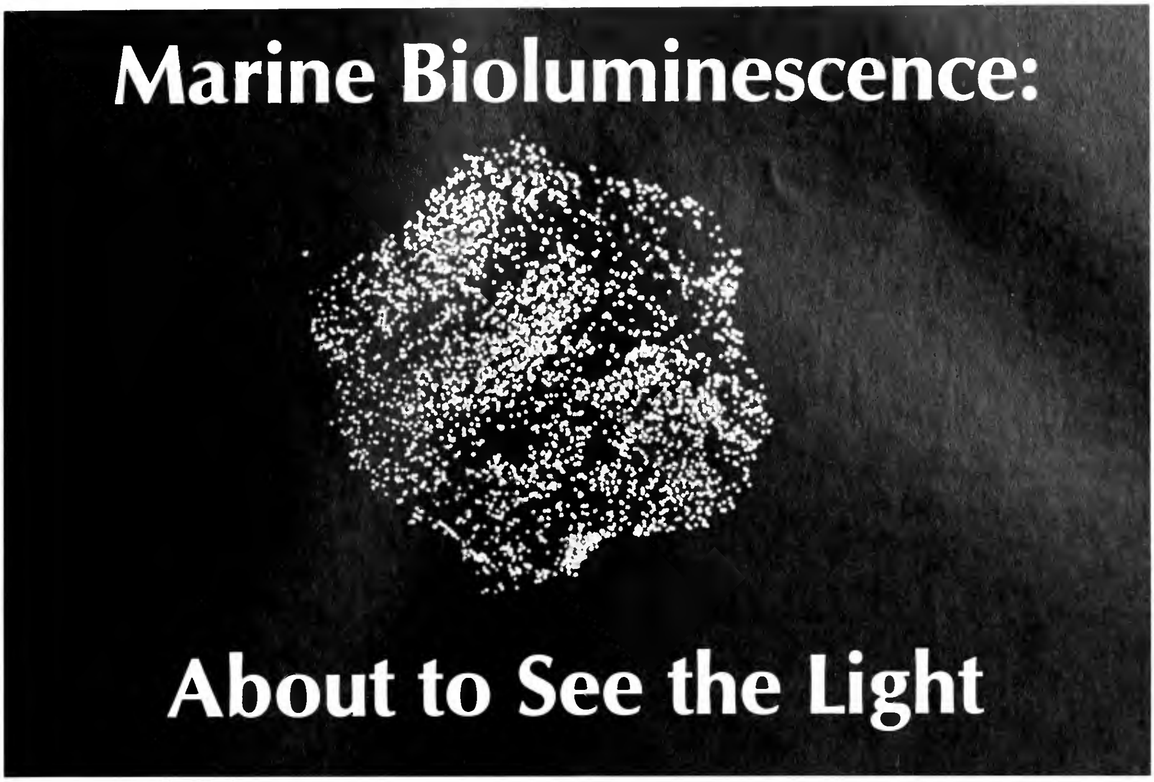
Marine Bioluminescence: About to See the Light



Bioluminescent bacteria grown in laboratory culture, photographed by their own light. (Photo by Kenneth Nealson)

by Kenneth H. Nealson and Charlie Arneson

Imagine, if you will, the following. It is approximately 350 B.C. Aristotle, who recently has thought out the laws of nature for presentation in his treatise *de Anima*, is walking through the forest on a dark evening. He notices a dim greenish glow emanating from a rotting tree stump. This violates one of his basic tenets: that it is a property of living things that they can be seen only if light shines on them. Aha, an exception to the rule! When he later discusses this observation with his students, they remind him of another exception: the eyes and skins of decaying marine fishes are often observed to emit a blue-green light. These two exceptions to the laws of nature are noted in his treatise with no explanation.

For many years luminescence of the kind seen by Aristotle was assumed to be connected with the decay process, and only in the late 18th century was convincing evidence presented that organisms (fungi and bacteria, respectively, in Aristotle's two exceptions) produce such lights, a phenomenon known as bioluminescence.

A Sea of Light

Bioluminescence is the emission of visible light by living organisms. The twinkling of fireflies on summer evenings is a familiar example, but the Aristotelian view that bioluminescence is a biological rarity is still prevalent, except among professional biologists. Actually, bioluminescent organisms are widespread and abundant. With more opportunity for travel and observation, Aristotle might have encountered insects infected with luminous bacteria, as well as luminous glow worms, fireflies, earthworms, and centipedes. Without an oceanic voyage, however, he still would have been left with the impression that bioluminescence is a scientific curiosity.

The oceans abound with luminous organisms; nearly every taxonomic group is represented. Below the photic zone—that uppermost layer of the ocean where light penetrates in sufficient quantities to allow photosynthesis—the dark, clear ocean is an excellent environment for the use of bioluminescence, and at greater depths, in the section of the ocean termed the midwater, it is the rule rather than the exception (Tables 1, 2, and 3). Among oceanic fishes, typically 65 to 75 percent of the species and 90 to 97 percent of the individuals collected are bioluminescent. Indeed, in the mesopelagic zone (which lies between 200 and 1,000 meters depth), bioluminescence is the major source of light in the environment.

Table 1. Properties of some marine luminous groups.*

BACTERIA

Bacteria (*Vibrio, Photobacterium*)
- Whole cell luminescence, continuous glow, soluble enzyme system
- Luciferin and luciferase characterized (structurally and functionally)
- Blue light commonly seen from bacterial associations: as saprophytes, parasites and symbionts with fishes and squids

DINOFLAGELLATES

Dinoflagellates (*Gonyaulax, Pyrocystis, Noctiluca*)
- Whole cell luminescence from subcellular organelles (scintillons)
- Flashes of 40–150 ms in response to physical stimulation
- Luciferase and luciferin characterized
- Luciferin binding protein that releases luciferin in response to pH change
- Major source of surface luminescence in the oceans
- Blue light

JELLYFISH AND SOFT CORALS

Cnidarians (*Aqueoria, Pelagia, Renilla*)
- Clusters of photocytes
- Flashes of 0.2–1.5 sec. or longer in response to mechanical stimulation
- Luciferase and luciferin characterized
- Luciferin binding proteins and photoproteins stimulated by calcium
- Some emit blue, others green light (green fluorescent protein used)

STARFISH

Ophiuroids (*Ophiopsila, Amphipholis*)
- Clusters of photocytes
- Flashes of two types (0.1–0.3 sec., and 20–60 sec.) in response to mechanical stimulation
- Neither luciferin nor luciferase purified
- Green light emitted

CRUSTACEANS

Ostracods (*Vargula, Cypridina*)
- Secretory cells (extracellular)
- Two types of flashes (1–5 sec.; 20–60 sec.) in response to mechanical stimulation
- Luciferase and luciferin characterized
- Extracellular blue light

FISHES, SQUIDS

Beryciform fishes (*Photoblepharon; Monocentris*)
Sepiolid squids (sepiola; euprymna)
- Specialized light organ to culture bacteria
- Neural control of luminescence
- Bacterial light continuous, mechanical control by host
- Blue light
- Duration of flash or glow dependent on the fish

FISHES

Batrachoidiform fishes (*Porichthys*)
- Discrete photophores
- Ventral luminescence
- Mechanism identical with that of ostracod crustaceans
- Flashes of two types (5–20 sec.; 2 minutes)
- Mechanism of control of blue-green light is unknown

* This table is not meant to be all inclusive, but only to demonstrate the range of luminous systems, some of which are well characterized, and others of which, like that of the starfish, are virtually unknown yet.

Unfortunately, studying bioluminescent marine organisms is often difficult. The mesopelagic zone—where the capacity to emit light is most abundant, and the uses to which light is put are most variable—is difficult and expensive to reach, and nearly impossible to study continuously enough for behavioral analyses. Furthermore, captured mesopelagic animals usually reach the surface dead or moribund; observations of the behavior of such moribund animals are always of dubious value.

Fortunately there are alternatives. Shallow-water animals closely related to some mesopelagic bioluminescent organisms can be maintained in the laboratory and studied. Since many mesopelagic animals have luminous organs that are structurally similar to those of their shallow water cousins, it is tempting to assume that the organs are used in a similar manner in the two groups.

The Chemistry of Light

From studies of shallow water and terrestrial bioluminescent animals, much is known about both the chemistry and the uses of bioluminescence in the oceans.

Bioluminescence is chemically generated, and, unlike electric light, heat is not produced in the process. Moreover, similar biochemical mechanisms underlie the production of light in all the myriad of organisms that are bioluminescent. In general terms, organisms use energy to excite, or raise the energy level, of molecules known as luciferins. This excited state is unstable, and the luciferin eventually decays into a variety of products, including light. The reaction is helped along by enzymes known as luciferases. Both "luciferin" and "luciferase" come from the Latin word "lucifer," meaning light-bringing. Luciferin and luciferase are generic terms used for a large number of different substrates and enzymes.

Many marine bioluminescent systems are not yet chemically characterized. Material is often difficult to obtain in sufficient quantities to allow chemical identification of luciferases or luciferins. Recently, techniques of genetic engineering have been used to clone the genes from luminous bacteria into more well-characterized laboratory bacteria. These studies have revealed that the regulation of bacterial luminescence is at the genetic level; the laboratory bacteria into which the genes from the luminescent marine bacteria had been cloned became luminescent. Moreover, from these laboratory bacteria, large amounts of normally difficult to obtain luciferins and luciferases can be obtained easily. Such approaches will prove quite useful in elucidating the biochemistry of other marine luminous systems. One wonders what Aristotle would have thought about these happenings.

Already we know that the chemistry and physiology of marine bioluminescent systems are impressively complex. Many luminous fishes and squid do not even generate their own light; instead they maintain cultures of symbiotic luminous bacteria in highly specialized organs. It is difficult to imagine that these diverse and complex chemical and biological systems evolved by accident or in the absence of strong selective pressure.

The Use of Bioluminescence

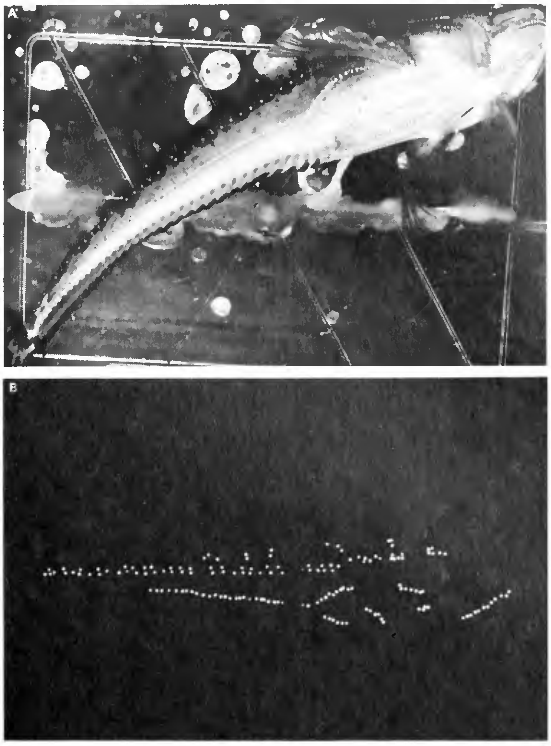
Four general uses of bioluminescence have been postulated: evasion of predators, obtaining prey, intraspecific communication, and advertisement

(Table 4). For example, fireflies use their luminescence to identify their species and sex to potential mates. All of the uses outlined in Table 4 are drawn from some specific organism, and most have been found in marine organisms. Some marine organisms use their light for more than one purpose. For example, the flashlight fish, *Photoblepharon palpebratus*, uses its light both to attract prey and to evade predators. The fish is normally found in large groups that may be visible for up to a mile; these glowing groups attract zooplankton, just as a bright light will attract moths and other insects. If approached by a predator, the flashlight fish will turn off its light—making itself momentarily invisible—and run away.

As one would expect, marine organisms have evolved so that their luminescence is as effective as possible within their environment. Most marine bioluminescence is blue-green, closely matching the optimal transmission spectrum of seawater. Near-shore organisms often show a luminescence more green than blue, mimicking the green-shifted transmission properties of coastal seawater. There are no chemical reasons why marine bioluminescence should be blue-green. Indeed, the luminescence of terrestrial organisms ranges over nearly the entire visible spectrum, all of which transmits well through the atmosphere. Thus, it appears that marine bioluminescence has evolved so as to be as visible as possible through the oceans.

Similarly, most marine organisms can best perceive the same colors of light as are emitted by most luminous marine organisms, leading one to suspect that the value of luminescence lies in it being seen (either by the same organisms that emit it, by predators, or by prey). This suggests that bioluminescence as we know it today evolved after eyes, perhaps quite recently in the fossil record.

More evidence that bioluminescence serves specific, vision-related functions is found in marine fishes and squid that emit light other than blue, and have visual pigments that are sensitive to these other wavelengths of light. Two possible reasons for the emission of such unusual wavelengths are illumination without detection and intraspecies communication. It seems obvious that the evolution of eyes and the evolution of bioluminescent systems have dramatically affected each other.



Bioluminescent fish. a) Porichtys myriaster *photographed in daylight. The twin rows of nodules visible on the underside are specialized light-producing organs called photophores. b) A closely related species,* Porichthys photophores *photographed by its own light. (Photos by J. Morin)*

Control of Bioluminescence

During the day, bioluminescence occurs primarily in the deeper parts of the ocean, whereas at night luminous activities are found much nearer the surface. In fact, some of the most brilliant displays of bioluminescence occur at the surface. Luminescent dinoflagellates (the organisms that cause red tides) can occur in sufficient concentrations that wakes of ships can be seen for miles, and fish can be seen easily in the water.

A key point is that bioluminescence is usually found in environments where it is sufficiently dark that the luminescence is of some use. This can be accomplished by living in deep, dark parts of the ocean; by vertical migration, coming to the surface at night and sinking to darker realms during the day; by

Table 2. Generalized zones, habitats, and processes of marine ecosystems.

Zones	Habitats and Organisms	Processes	Comments on Bioluminescence
Epipelagic (surface)	Photic zone	Primary producers	Luminescence dominated by dinoflagellates and crustaceans Luminescence primarily nocturnal Surface displays can be quite bright
Upper Mesopelagic (midwater)	Euphotic zone	Nutrient recycling	Active bioluminescent zone Maximum intensity of flashes
	Dominated by vertical migraters Deep scattering layer		Maximum intensity of sustained luminescence Region of counterillumination Limit of human visual sensitivity
Lower Mesopelagic			Bioluminescence is major source of ambient light in environment
Bathypelagic (deep water)	Aphotic zone (low biomass)	Low activities	Low levels of bioluminescence

Table 3. General properties of coastal and oceanic luminescent organisms

	Coastal	Oceanic (mesopelagic)
Major representative groups:	Dinoflagellates, hydrozoans ctenophores, ophiuroids	Crustaceans, cephalopods, fishes ctenophores, scyphozoans
Percentage of species that are luminous	1–2%	60–80%
Structure of the luminescent system	Simple photocytes and photosecretory cells	Complex photophores or light organs
Duration of emitted light:	Flashes 0.04–2 sec. Glows of 5–100 sec. Contact stimulation	Highly variable Complex triggering
Color of emitted light:	Variable, mostly green	Mostly blue
Visual systems of luminous organism:	Poorly developed or absent	Well developed and complex
Behavioural capacity:	Limited and simple	Complex
Motility:	Sessile or sedentary	Highly motile, swimming
Mode of feeding:	Suspension feeders or autotrophs	Active predators, carnivorous
Habitat:	Complex and heterogeneous	Relatively homogeneous
Ambient light levels:	105-10-16 uW cm-2	10-1-10-21 uW cm-2
Primary functions of bioluminescence:	Deter predation	Multiple and variable

For detailed explanations of these properties, see article by Morin (1983).

being nocturnal; or by having control over the light-emitting process so as to use it only at night.

Given these constraints on the distribution of bioluminescence, most studies of the phenomenon consist of locating and quantifying luminescent activities and then attempting to isolate the luminescent organisms by trawling or pumping methods. Naturally, such studies tend to pick up the peaks of luminescence rather than the ordinary levels, and so give us a biased impression as to the ordinary level of bioluminescence present. In addition, trawling and pumping methods do not necessarily retrieve a representative sample of all the luminescent organisms that are present in the water. Plankton nets used to sample microscopic dinoflagellates are inappropriate for sampling luminescent squid. Such methods, however, have been the best available, and have added immensely to our appreciation of the amounts and kinds of oceanic bioluminescence. But examining the activities of luminescent organisms in their natural environment over extended time periods clearly would be preferable.

Scripps Canyon Sea Structure

To study bioluminescence on time scales longer than hours, we constructed a moored, automated observation system offshore of the Scripps Institution of Oceanography, where there are several deep canyons with substantial luminescent activity in the evenings. By virtue of their connections with deeper areas, these canyons are thought to mimic in many ways the mesopelagic zones of the ocean.

Our observation system consists of a buoy moored below the surface that supports light detectors aimed toward both the seafloor and the surface. These photometers are connected to the laboratory by a submarine cable. In the lab, it is possible to observe luminescent activity through the photometers as well as to store the data for later analysis. Other instruments measure temperature, depth, and current velocity and direction.

Studies during the last two years show that the instruments are unaffected by surface waves—a sharp contrast to the situation when studying luminescence from ships. Since many luminous organisms are mechanically stimulated to flash, such independence of wave effects is essential if one is to get some feeling for the natural (unstimulated) levels of light emission. But ideally, we would like to be able to identify the organisms responsible for the luminescence without going to collect them, something we cannot yet do with our system.

Songs in Blue Light

An avid birdwatcher often can identify an unseen

Table 4. Behavioral functions of bioluminescence.*

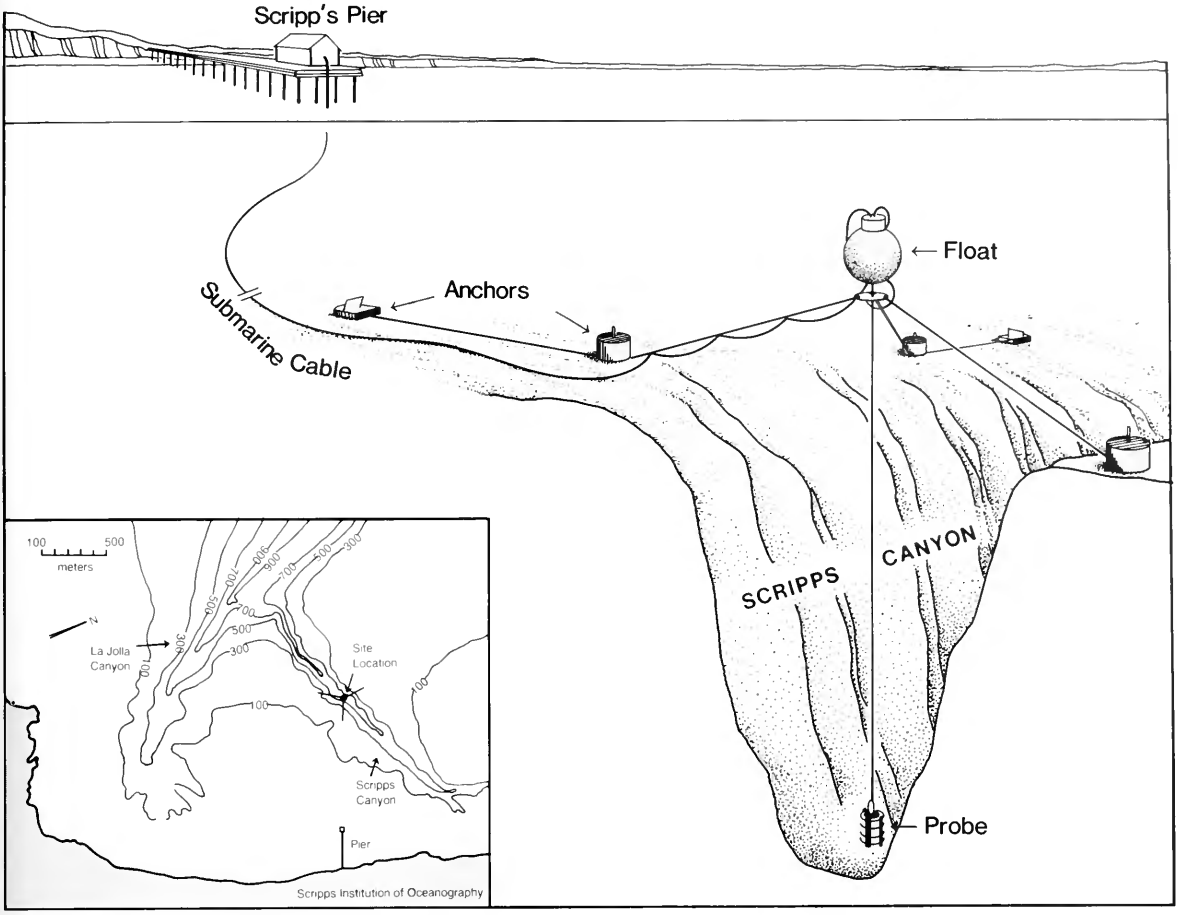
Evasion from Predators:
- Repelling Effect, where surprise flash is used by prey to ward off predator.
- Flashbulb Effect, where bright flash or glow is used to temporarily blind predators.
- Decoy Effect, where chemical secretions or autotomized luminous structures are used to confuse predators.
- Burglar Alarm, where luminescence is used to reveal predator to its own predators.
- Camoflage Effect, where luminescence is used for counterillumination or for disruptive illumination in order to hide from predators.

Obtaining Prey:
- Lure Effect, where prey are lured to light either by general illumination or by specific lures.
- Flashlight Effect, where luminescence is used for visual location of prey.

Intraspecific Communication:
- Reproduction Uses, where luminescence is used for courtship or mating signals.
- Spacing Effect, where luminescence is used for territorial signals, or for aggregation mechanism.

Advertisement:
- Where the light of one species is detected by another to the mutual benefit of both.

* Not all of these proposed functions have been delineated for marine organisms, but each has been seen for some known organism, and it seems likely that all (and perhaps many more) exist in the myriad of marine luminous forms known and to be discovered.



Through the use of this moored system, bioluminescence can now be studied in the field on a continuous basis. The float and probe are unaffected by surface waves, and are connected to a computer ashore. Sophisticated versions may well allow scientists to study the behavior of bioluminescent organisms without capturing them.

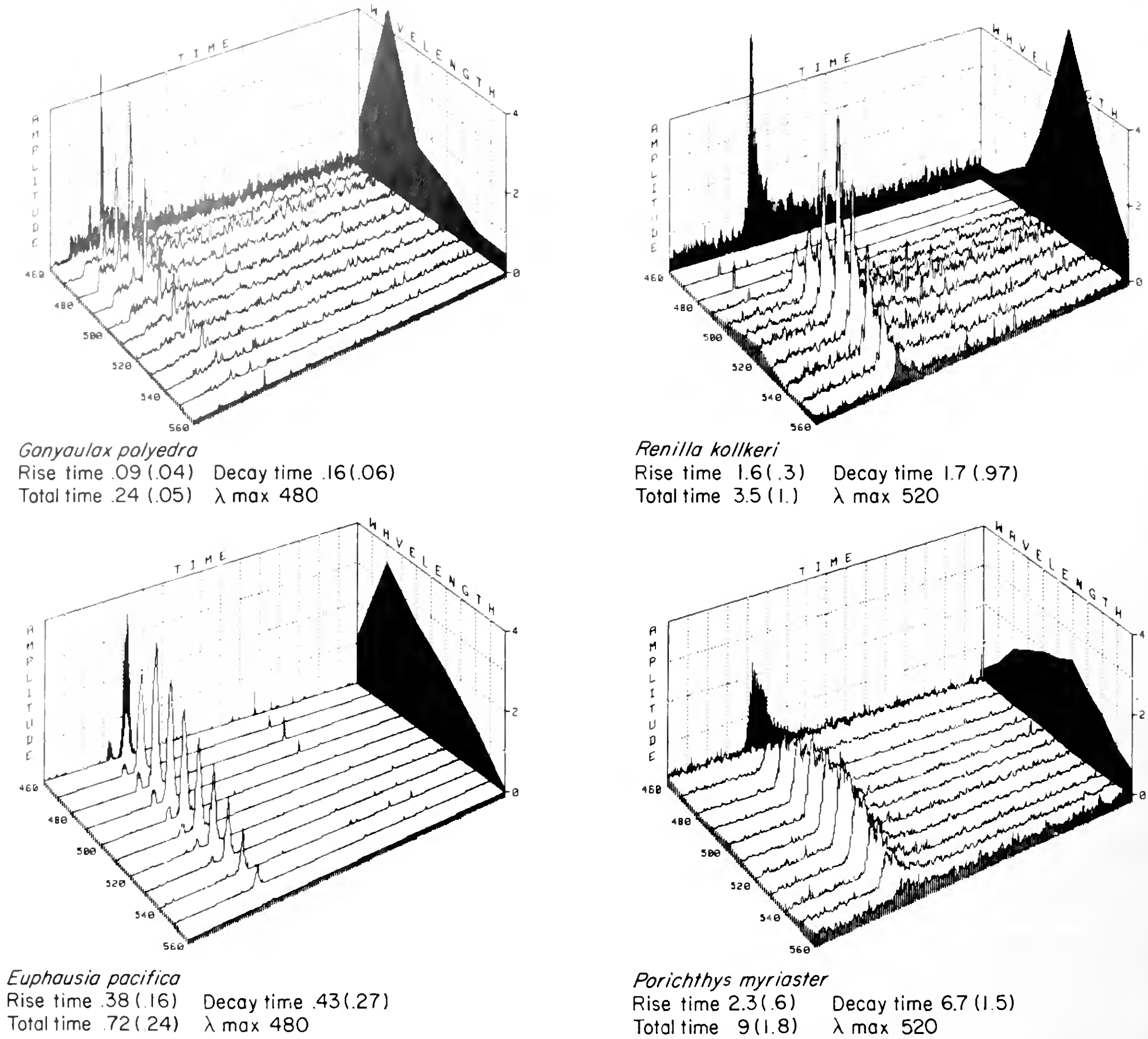
bird by the pitch and rhythm of its song. Such aural cues work when vision reveals nothing more than a small patch of brown feathers, or even when the bird is out of sight. Similar considerations apply in studying luminescence.

Each luminescent species has its own light signature. Most oceanic organisms flash rather than glow, and the flashes are often distinct in form and time. The characteritics that vary are rise time, decay time, and total flash time. In addition, luminous organisms emit different colors of light. Although most marine luminescence is blue-green to the eye, there are nevertheless interspecific differences than can be detected with sensitive instruments. The combination of such spectral and kinetic properties may provide a luminescent "signature" as distinctive as the chirp of a chickadee or the rattling call of a kingfisher.

Our first attempts in this direction involved a simple device using six filtered photometers that could detect 6 different wavelengths of light, as well as the kinetics of the flash. The device was set up in the laboratory to continously observe and record flashes from luminescent organisms in a small aquarium. Preliminary data from this device indicate that easily distinguishable signatures exist for different species. But this instrument is not suitable for field use. It requires 6 high-voltage power supplies and must be calibrated each day. Furthermore, the spectral resolution of the device (only 6 wavelengths are measured) is probably insufficient for distinguishing species in a mixed culture.

More recently we have replaced the photometer array with a solid state light sensing device called a charge coupled device (CCD). The CCD can be powered by batteries and is easy to calibrate. Moreover, it can analyze up to 64 wavelengths of light, offering much greater resolution than with the previously described system. Eventually the CCD may allow the observation and identification of organisms in the field—defining natural population levels, studying the interactions of luminescent organisms, and assessing the activities and movements of luminous organisms.

Such continuous observation of the bioluminescent life of the deep ocean would allow us to study a realm of light that Aristotle never imagined. It should be a valuable addition to the



Three dimensional plots of flashes from different organisms. Shown just below each figure are the means and standard deviations (in parentheses) of rise time, total time, and decay time for 15 flashes of each species. Also shown is the wavelength of maximum intensity for each species.

tools available to marine scientists trying to understand bioluminescence and ecological relationships in mesopelagic communities.

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Suggested Readings

Harvey, E. N. 1952. Bioluminescence. Academic Press, N.Y. 649 pp.

Hastings, J. W. 1983. Biological diversity, chemical mechanisms, and the evolutionary origins of bioluminescent systems. J. Mol. Evol. 19: 309–321.

Herring, P. J. 1978. Bioluminescence in Action. Academic Press, N.Y.

Morin, J. G. 1983. Coastal bioluminescence: patterns and functions. Bull. Mar. Sci. 33: 787–817.

Nealson, K. H. 1981. *Bioluminescence: Current Perspectives.* Burgess Publ. Co. Minneapolis, Minn. 165 pp.

Nealson, K. H., A. C. Arneson, and A. Bratkovich. 1984. Preliminary results from studies of nocturnal bioluminescence with subsurface moored photometers. Mar. Biol. 83: 185–191.

Nealson, K. H. and R. Cassin. 1984. Molecular genetic studies in bioluminescence. pp. 87–99 In: *Analytical Applications of Bioluminescence and Chemiluminescence*, L. J. Kricka, P. E. Stanley, G. Thorpe, and T. Whitehead eds. Academic Press. N.Y.

Shimomura, O. 1982. Mechanism of bioluminescence. pp. 249–276 In *Chemical and Biological Generation of Excited States.* Academic Press, Inc. N.Y.

Warner, J. A., C. Arneson, R. W. Austin, D. Bailey, G. Huszar, P. James, R. McConnaughey, K. Nealson and E. Stephan. 1984. Scripps Canyon sea structure: A design and deployment for the study of oceanic bioluminescence. Mar. Technol. Soc. Journal. 17: 40–47.


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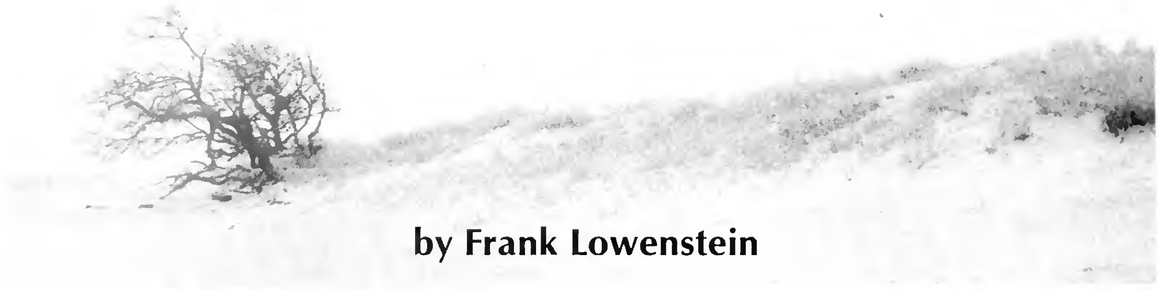
Beaches or Bedrooms—



by Frank Lowenstein

Up and down the East and Gulf Coasts of the United States, homes, hotels, condominiums, and resorts are being built rapidly on land that more and more scientists are convinced is unsuitable for such uses. As these scientists begin to publicly express their views, many developers and homeowners are becoming outraged at what they perceive as meddling in their affairs.

Snap Shots

Scenes of conflict between people and natural processes are common all along the coast:

Each winter since 1952, Virginia Beach, Va., one of the largest coastal resorts on the East Coast, has had to move sand from local inlets and inland deposits of sand to the beach. Not just a little sand either: the equivalent of 30,000 dump trucks' worth of sand a year are required (at a cost of $1.5 million each winter), and even with this generous subsidy, just a thin strip of beach is maintained. The hotels cast shadows completely across it by early afternoon. The U.S. Army Corps of Engineers is considering a project to double the width of the beach, a task that would require 2 million cubic yards of sand—the equivalent of 200,000 full dump trucks. For the residents and business people of Virginia Beach, a look ahead shows an endless and expensive series of offerings to the storm gods and the seas.

A few miles south, the wealthy beachfront community of Sandbridge, Va., is making a losing stand against the sea. A winter trek along the beach after a mild storm shows the aftermath of waves frolicking among the houses: a collapsed stairway, its foundations eroded out from under it; a beachfront house separated from the sea only by a cracked and undermined wall of rocks; drifts of sand across roads, driveways, and doorways. During

Coastal communities are increasingly threatened by a one-two punch of rising sea level and storm damage. Here homes in Scituate, Mass., are overwhelmed in a 1978 storm. (Photo courtesy of the Federal Emergency Management Agency)

The Choice as Sea Level Rises

powerful storms, the ocean can roll right through the community, and most homes are raised up on tall pilings in hopes that the waves may pass underneath. To the residents of Sandbridge, the future promises an endless procession of mountainous waves rearing up to smash their homes.

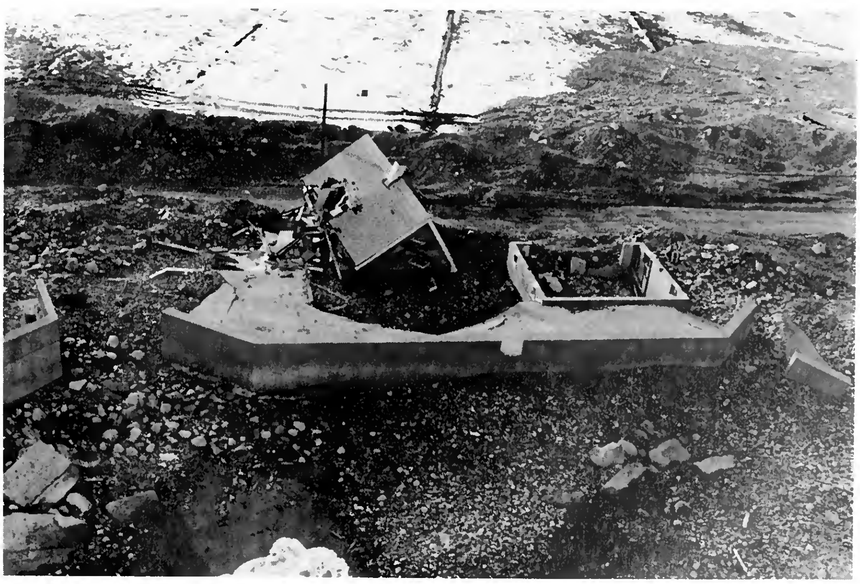
Seabright, New Jersey, is built on a narrow spit of sand between the ocean and the estuary of the Shrewsbury River. It is protected by a massive seawall, but in a powerful nor'easter in the spring of 1984, "the ocean came right over the wall and ran down to the river," according to Kenneth Johnson, the police chief. The problem is clear in his eyes. "Where there used to be beach, there's no beach at all; the water's right against the wall. It's cut out so bad that the wall is settling down."

Shifting Sands

The troubles these communities face stem from their common situation—all are built on the coastal barriers of the United States' East Coast. Coastal barriers, also referred to as barrier beaches and barrier islands, are long strips of sand that parallel the coast from the Rio Grande to the eastern tip of Long Island, with scattered examples along the coast of New England. Typically, coastal barriers consist of a wide beach, backed by dunes, and behind that a marshy lagoon stretching to the mainland.

The long sweeps of sand and exposure to the ocean make these beaches among the most beautiful in the country—Miami Beach, Atlantic City, and virtually all other well-known coastal resorts in the East are located on coastal barriers. The marshes they shelter are vital habitats for waterfowl and fish. According to the U.S. Department of Interior, 80 percent of the fish caught off the East Coast are dependent on these marshes at some point in their life cycle.

Barriers take the brunt of the major storms that strike the coast. To pass through relatively unscathed, the barriers must absorb the energy of



A Scituate home after the storm had passed. (Photo courtesy of the Federal Emergency Management Agency)

The scalloped edge along the backside of this barrier island is formed by sand from the beach, which was carried across the island by storm waves, a process known as overwash. (Photo by Jack Schnable)

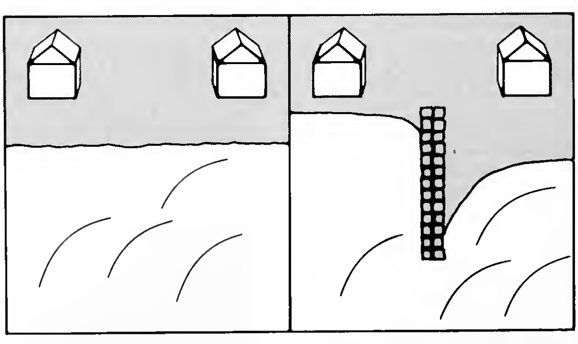
the storm waves. One of the ways that wave energy is absorbed is through the movement of sand. Waves may move sand from the beach to offshore areas or, conversely, into the dunes; they may erode the dunes, depositing sand onto the beach or carrying it out to sea; or they may carry sand from the beach and the dunes into the marshes behind the barrier, a process known as overwash. The common factor is movement. Just as a flexible reed may survive a wind that destroys an oak tree, so the barriers survive hurricanes and nor'easters not through unyielding strength but by giving before the storm.

This picture changes when a barrier is developed for homes or as a resort. Storm waves that previously rushed harmlessly through gaps between the dunes now encounter buildings and roadways. Moreover, since the dynamic nature of the barriers is readily perceived only during storms, homeowners tend to attribute damage to a particular storm, rather than to the basic mobility of coastal barriers. With their homes or investments at stake, local residents are more likely to seek to hold the sand in place and the waves at bay than to admit that development was improperly placed to begin with. Such efforts to hold the barrier beaches in place are like trying to brace a reed against the wind—they usually don't work, and may destroy what they are supposed to preserve. As Douglas Inman, Director of the Center for Coastal Studies at the Scripps Institute of Oceanography, puts it: "When you try and hold a barrier-type formation in place, you're in trouble."

The main methods of trying to hold down the barriers are beach nourishment, groins, and seawalls. All have disadvantages.

Beach nourishment—dumping large quantities of sand on the beach—is the least troublesome of these methods. It can actually work for a time, and has no negative effects on other areas, but it is quite expensive. A recent Army Corps of Engineers project to restore the beach to Miami Beach cost about $65 million—for less than 25 kilometers of coast. Additionally, the added sand usually erodes more quickly than the native sand, for two reasons. By adding sand to the beach and not adding it to offshore areas, beach nourishment throws the slope of the beach out of equilibrium with adjacent underwater areas, steepening the profile of the shoreface (which includes both the beach and areas just offshore). This steeper profile is unstable in storms; the waves move sand offshore to reflatten the profile to its equilibrium slope. This flattening process moves the shoreline back. In other words, given a certain sea level, the sea will encroach farther horizontally after the slope has been reduced by flattening than it does on the steep slope existing immediately after beach nourishment. This process can cause rapid shrinkage of the newly nourished beach. Additionally, sand used for beach nourishment often includes many fine particles of silt and clay, which will be washed away when exposed to the force of the waves, reducing the volume added to the beach. These two factors—the changed slope and texture of the sand—mean that beach nourishment must be renewed again and again to be effective. "Even wealthy communities can't keep it up forever," notes Orrin Pilkey, Professor of Geology at Duke University.

Groins have different problems. A groin is a barrier, usually rock, built perpendicularly to the shore, with the intent of trapping sand moving parallel to the shore. Since there is usually a net flow of sand in one direction along the coast, the sand trapped by the groins may be severely missed downdrift. The same forces that cause a flow of sand to exist in the first place continue to strip sand away from such downdrift areas, causing them to shrink. The situation at Westhampton Beach, N.Y., is typical. When an erosion-control project for the beach was first designed by the Army Corps of Engineers in the early 1960s, it called for only a few groins in the areas of highest erosion, and for a large addition of sand to the beach. However, according to Gilbert Nersesian, a coastal engineer with the Corps, pressure from local residents forced the Corps to change the design to include more groins and no additional sand. Between 1965 and 1970, a series of storms stripped away sand from areas downdrift of the groins. In 1970, four more groins and some sand were added, but the



When waves approach the shoreline at an angle, they cause sand to move along the shore in the direction of their movement. A groin interrupts this flow, trapping sand above it and causing increased erosion downdrift from it.

situation improved little. Today, in the heavily eroded areas of Westhampton Beach high tide actually goes under many homes, which are raised about 5 meters above the beach on pilings to avoid water damage. Nersesian estimates 20 homes have fallen into the ocean during the last 10 years. Although a groin eventually may trap so much sand that it ceases to function, it still alters the pattern of the waves and currents, and so may continue to exacerbate erosion downdrift.

Seawalls (and their relatives, revetments and bulkheads) are massive barriers intended to stop waves from reaching the areas behind the wall. In this they are effective. For example, after a 1900 hurricane caused 6,000 deaths in Galveston, Texas, the city built a seawall more than 5 meters tall that has prevented any further deaths. Unfortunately, like most quick-fix solutions, seawalls have side effects.

On an open beach, waves expend much of their energy moving across the beach. Seawalls cut this process short, reflecting wave force seaward, where it can cause significant erosion of the beach and may eventually eliminate the beach entirely. In the process, seawalls doom themselves. "The more energy that comes in, the more sand moves," according to Paul Jeffrey Godfrey, Associate Professor of Botany at the University of Massachusetts at Amherst and one of the first scientists to document the dynamic nature of the barrier beaches. Once the sand is disturbed, it may be transported either offshore or along the shore, in either case, away from the wall. "These things fail because they get undermined and fall over," Godfrey explains. Ultimately, the beach disappears, the wall falls over, and a new, larger, more expensive wall must be constructed. Seawalls may also fail in other ways; for example, water that builds up behind the wall from rainfall, waves flanking the wall, or other sources can actually topple the wall forward, onto the beach. Once again, a larger, stronger, more expensive wall is the usual answer. As Pilkey and Wallace Kaufman wrote in *The Beaches Are Moving*, "The advent of the wall transforms the active recreation of swimming and beachcombing into the passive recreation of looking over a wall—if it's not too high."

Because they reflect the force of storm waves back onto the beach, sea walls tend to undermine themselves and collapse. Here a section of wall in Marshfield, Mass., is replaced after its destruction in a 1978 storm. (Photo by Jeff Benoit, Mass. Coastal Zone Management)

Rising Seas and Drowned Islands

The dynamic nature of the barriers and the relative inefficacy of shoreline protection has been known for some time (see *Oceanus*, Vol. 23, No. 4), but recent research has uncovered some facts that paint this bleak picture even bleaker.

Two recent studies have tackled the question of future sea-level rise, with distressingly similar conclusions. A 1983 study by the U.S. Environmental Protection Agency (EPA) predicted that, because of global warming, sea-level rise would be between 0.6 and 3.3 meters by the year 2100. In contrast, according to EPA, sea-level rise based on historical rates would be only 0.1 to 0.18 meters. A 1983 report from the National Research Council of the National Academy of Sciences predicted a rise of between 0.5 and 0.9 meters during the next century, and warned of the possibility of a 5 or 6 meter rise in the next several centuries. These estimates assume that the increasing levels of carbon dioxide and other gases in the atmosphere from industrial activity, the burning of fossil fuels, and progressive deforestation will cause a global warming trend by trapping heat within the atmosphere—the greenhouse effect. If the predicted warming occurs, it will increase sea level in two ways: by melting of glaciers and ice caps and by raising the temperature of the upper layers of the ocean, thereby causing the volume of the water to increase—a process known as thermal expansion. "I think it's clear that there's going to be an acceleration in the rate of sea-level rise. That's pretty solid," notes David Aubrey, Associate Scientist in the Geology and Geophysics Department at the Woods Hole Oceanographic Institution (WHOI).

A related effect, according to Aubrey, may be an increased incidence of storms and hurricanes, caused in part by the warming of the ocean's surface. Such an increase would spell disaster for barrier beach residents.

Moreover, sea-level rise affects the coast

This house was severely damaged by a storm in 1978. When rebuilt, it was raised on pilings so that storm waves pass under instead of through it. The extra care proved its worth in the 1984 storm shown here. As sea level rises, however, the coastal barrier on which the house is built will retreat, and the house will seem to move out to sea. Such storm-proof structures eventually impinge on both the aesthetics and recreational utility of the beach. (Photo by Jeff Benoit)

directly in a number of ways. The most obvious is that low-lying coastal areas are inundated. On the barriers, if they were to remain stationary, the sea would encroach from both the ocean and lagoon sides, reducing the area of the barriers and drowning low-lying ones.

But coastal barriers have been subjected to rising sea level for 15,000 years, and would not still be around if they were so easily destroyed. As the sea rises, the lagoons encroach onto the mainland, the dunes cover the former location of the lagoons, and the beach moves back to where the dunes were. After the sand has settled, the whole system has leapfrogged back and, because the coastal plain is somewhat sloped, has moved to a higher elevation, thus temporarily escaping the rising sea. When coastal communities institute shoreline protection measures to save structures located near the ocean, they block this natural escape valve. "The neat thing about the natural systems is that they're adapted to that movement," notes Godfrey. "The trick for human beings is to learn how that works."

The predicted acceleration of sea-level rise does not allow much time for us to learn. According to coastal geologists, on the East Coast any given rise in sea level causes 10 to 1,000 times as much horizontal shoreline retreat. Thus, if the high end of EPA's range of predictions is correct, the shoreline in some areas of the East might retreat as much as 3 kilometers by the year 2100, a magnitude of retreat that suggests we had better begin planning immediately how we are to adapt. Such predictions of coastal retreat are based on the Bruun Rule, introduced by Per Bruun, a consulting engineer based in South Carolina, in 1962, which states that in the face of rising sea level, the coast will maintain the same basic profile but move inland, up the coastal plain. Unfortunately, the Bruun Rule may be optimistic, primarily because of its prediction that the shape of the shoreface will remain the same.

Bruun Revised and Barrier Beach Equilibrium

"I think the Bruun Rule can be chucked out the window," states Aubrey. Among his chief misgivings about the rule is that it assumes that the average force of the waves striking a beach will remain constant as sea level rises. But if storm frequency increases this premise is likely to be false. It also would require an "almost infinite" amount of sand. That is, if the beach is to move back along the entire coast, at the same time retaining a constant volume of sand above sea level, then a vast amount of sand will be needed from some source to fill in the area in front of the beach. Where would the sand come from?

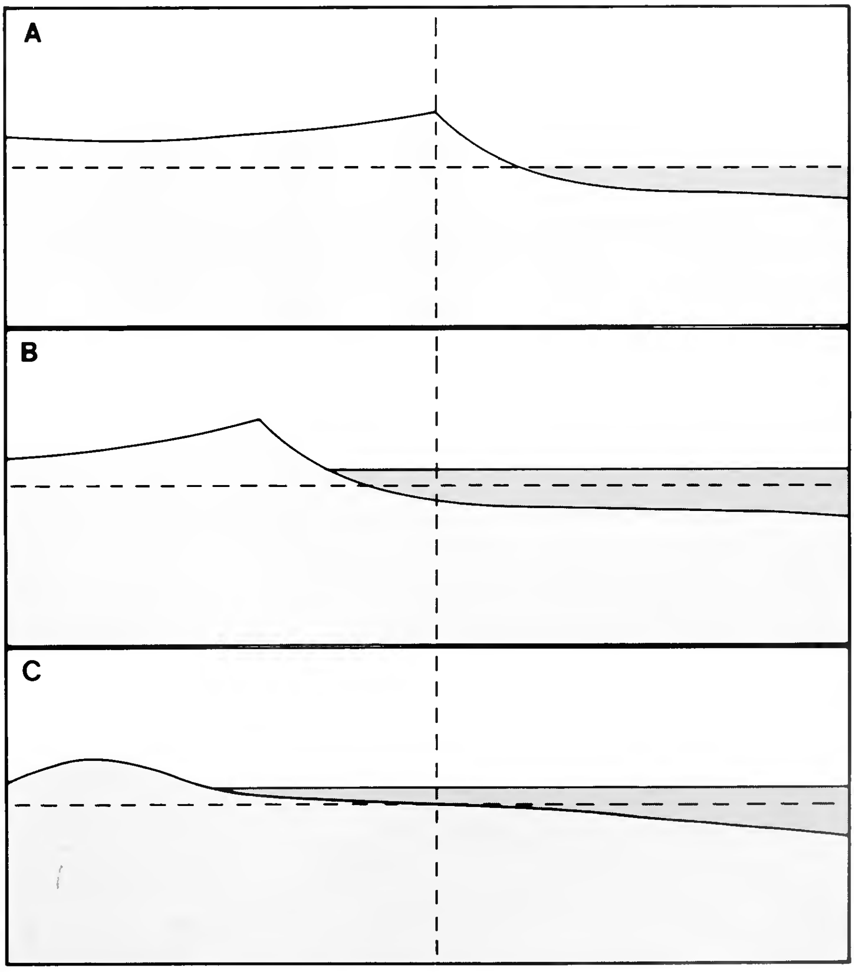
A more likely situation, according to Aubrey, is that the profile of the beach will flatten out as sea level rises in response to increased storm frequency. This would provide sediment to fill in the area formerly occupied by the beach, and also would be expected because the deeper water offshore will allow larger waves to strike the beach as sea level rises.

Most of the energy in a breaking wave is lost through friction as the wave rushes up the beach and through attrition as the water percolates into the sand. If the width of the beach is insufficient for this to occur (as is the case during large storms) then the waves will begin to move the sand around, usually carrying some offshore and eroding some away from the top of the beach and the dunes. The effect of this is to create a flatter shoreface, which allows the waves more space to dissipate. Since the ocean can encroach farther up such a flattened profile, and since he expects the storms that produce such effects to become more common, Aubrey predicts sea-level rise will bring even more rapid coastal retreat than is predicted by the Bruun Rule.

Recently, geologists have uncovered still another aspect of barrier-beach dynamics that bodes poorly for the future of barrier beach communities. Stephen Leatherman, Professor of Geography at the University of Maryland, has found that rising sea level and storms can interact to launch a surprise attack. While studying shoreline retreat at Ocean City, Maryland, Leatherman noticed that the shoreline had retreated hardly at all in the last 20 years, although the historical record shows an average rate of retreat of 0.6 meters a year for the last 150 years. Moreover, when Leatherman looked at what was happening underwater, he found that retreat was proceeding at a faster pace at a depth of 20 feet than at 10 feet. In short, the shoreface was steepening underwater. This steep slope may be unstable when a major storm next strikes, and Leatherman believes such a storm could produce 15 to 30 meters of shoreline retreat in a matter of hours, returning the shore to a flatter, more stable slope. "I think sea-level rise is the driving force," Leatherman explains. "It puts the shoreline out of equilibrium, but storms provide the geologic energy to put it back into equilibrium." Such a rapid retreat would cause tremendous damage to coastal barrier communities, and would allow essentially no time to implement measures to moderate the effects.

Hurricane Coming

There also is an immediate danger to human life involved in the heavy development of coastal



According to one theory of coastal dynamics, when sea level rises from its current level (A) to some higher level (B), the shoreface retreats but retains the same profile. Some coastal geologists, however, have come to believe that instead of retaining the same profile, the shoreline would flatten out as sea level rises, resulting in much greater landward retreat of the shoreline (C), and consequently, much greater disruption of coastal communities.

The Not So Wild West

"The problem on the West Coast is totally different," explains Douglas Inman, Director of the Center for Coastal Studies at the Scripps Institute of Oceanography. "Erosion is less due to sea-level rise than to the cutting off of the supply of sediment." In contrast to the broad coastal plains of the East, the West Coast is characterized by narrow beaches backed by cliffs and mountain ranges. This rugged landscape results from the collision of the North American and Pacific plates, which have been grinding against each other for millions of years, buckling up the land along the boundary in the process. As a result the West Coast is rising about as fast as sea level, so that the apparent rise in sea level is small or even nonexistent. But like the problems on coastal barriers, West Coast problems stem from man's alteration of a system in dynamic equilibrium.

Most sand on Western beaches comes from the erosion of sea cliffs and from rivers, which carry sand from the mountains to the coast. In recent years, man has reduced the width of Western beaches dramatically through an action that does not even take place near the coast. "Sediment is being cut off from the rivers by dams for flood control, reservoirs, and irrigation," explains Inman. "Since we don't have a source of sand, the beaches are disappearing."

Nor has the erosion been limited to the beach. Where previously the beaches served to protect the bluffs from the force of storm waves, now the waves can roll across the narrowed beaches without losing much energy, causing rapid erosion of the sea cliffs. The retreat of these cliffs can provide sand to replace that lost behind the river dams, but in the process, homes and roads built on the bluffs may be endangered.

Moreover, development atop the bluffs often increases erosion. Homesites are often graded into unnatural and unstable slopes, which then erode more rapidly. Houses also bring septic systems and landscaping with non-native plants that require watering. Both of these increase the ground water level, which also makes bluffs more prone to erosion. Problems as a result of river damming and development are most noticeable in Southern California, where these activities are more common than in the Pacific Northwest. As on the East Coast, shoreline protection measures may only aggravate the situation, since they do not address the basic problem—a shortage of sand on the West Coast and rising sea level on the East Coast.

A West Coast house destroyed by storms (L.A. Times photo)

Coastal erosion in the West varies greatly from year to year, in part because of the episodic occurrence of stormy periods there. According to recent research by Gerald Kuhn and Francis Shepard, both geologists at Scripps, stormy periods and, consequently, periods of high erosion appear to follow major volcanic eruptions, with relatively calm periods in between these events. As one consequence of this pattern of infrequent but dramatic erosion, the effects of development and river damming on the beaches and sea cliffs of the West Coast are difficult for coastal residents to perceive. When erosion occurs, it is blamed on the unusual storms, not on coastal development or dams that may be hundreds of miles away.

Erosion also varies with the types of rock that compose the cliffs behind the beach. Sediments not yet formed into rocks and very soft rocks erode quite easily. Granitic shorelines erode very slowly. Some types of sandstone give the appearance of stability, with long periods of little change followed by large landslides. These factors make coastal retreat on the West Coast quite variable locally, furthering the perception that there is not a larger problem.

If sea-level rise accelerates as predicted, then accelerated rates of coastal retreat will occur all along the West Coast, and communities there will increasingly find themselves facing the same dilemmas that confront their East Coast cousins: whether and how to limit development to locations where it will not be destroyed. **—FL** barriers. Most such areas are separated from the mainland by marsh or lagoon, and there may be only one or two bridges providing access to the barrier. As a result, on most developed coastal barriers, the time required for people to evacuate greatly exceeds the amount of warning that will be available in the event of a storm. Evacuation times typically run over 18 hours, and often over 24. But according to Neil Frank, Director of the National Hurricane Center (NHC), "I'm just not going to be able to give you warnings of 24 or 36 hours." Currently the NHC tries to give 12 hours warning for evacuations.

At the "Cities on the Beach" conference held last January in Virginia Beach, Frank used the case of Hurricane Alicia, which hit Galveston, Texas, on August 18, 1983, to illustrate his point. Twenty-four hours before it hit, the storm was a weak hurricane headed for Corpus Christi. The National Hurricane Center did not issue any warning for Galveston. Twelve hours before it hit, the storm had intensified significantly and turned toward Galveston. By then it was too late to evacuate the city; a full 26 hours would have been needed. Not until a mere six hours before the storm made landfall did it intensify to a Category 3 storm, the middle of the NHC's five-point scale.

Although it was too late to evacuate, residents not protected by Galveston's 5-meter-high seawall were moved to behind the seawall. As a result, Alicia caused no deaths on Galveston Island, but it did cause nearly $700 million in property damage, primarily in those areas of the city not protected by the sea wall.

"Alicia was almost the meteorological disaster we've been afraid of," states Frank. But within a year federal flood insurance monies were being used to rebuild the homes, condominiums, and hotels that had been destroyed in the storm. According to Frank, one condo even advertised, "You don't have to live behind the seawall."

With each passing year, the increasing development along the coast increases evacuation times, and Frank is worried. With current technology, in order to be sure of warning those who might be hit by hurricanes, the NHC would have to issue false alarms in four out of five cases.

Cities on the Beach

At the Cities on the Beach conference, coastal geologists, engineers, planners, and government officials came together to analyze the problems facing barrier beach communities. For the residents of such communities, the consensus was not encouraging. Although billed as a conference on managing developed coastal barriers, most speakers instead emphasized the need to prevent or slow further development on the barriers.

Lieutenant Colonel Ronald G. Kelsey, Assistant Director of Civil Works and Environmental Programs for the U.S. Army Corps of Engineers, pointed to a fundamental choice: "We're either going to find a better way to use the coast, or go from one headache to another."

J. Craig Potter, Acting Assistant Secretary of Interior for Fish and Wildlife and Parks, sounded the same note, arguing that uncontrolled development must be prevented. "The beach is inherently a dynamic system and any attempt to make it stable by ... construction of groins, seawalls, bulkheads, and other engineering devices ... is ultimately self-defeating. While such a strategy might be successful in the short run, in the long run attempts to save a beach by stabilizing it frequently result in destroying it."

Pilkey presented his view of the nation's ultimate choice, stating, "In the long run you can have beaches, or you can have buildings, but you can't have both." Given the tremendous ecological importance of the barriers, and the fact that it is the beach that draws people to the shore in the first place, Pilkey then argued that we should either move buildings back from the shore, or "let them fall in." At this point, four New Jersey homeowners attending the conference stood up and walked out in protest. As Susan Halsey, coastal geologist with the New Jersey Department of Environmental Protection, noted after Pilkey's speech, "This is not something that the public is ready to hear."

Nowhere is this gap between what scientists believe and what the public is willing to hear more visible than in the furor that surrounds the federal government's strongest move toward coastal barrier conservation, the Coastal Barrier Resources Act (CBRA).

Not On My Barrier

Enacted in 1982, the Coastal Barrier Resources Act was intended to minimize the loss of human life by keeping the number of people living on coastal barriers as low as possible, to reduce the expenditure of federal monies in support of development that is by its very nature prone to damage, and to reduce the damage to natural resources that often occurs when coastal barriers are developed. To accomplish these broad goals the act took an unusual tack: it prohibited nothing, and bought nothing. Instead it merely eliminated, on specifically designated undeveloped barriers, federal subsidies for such items as roads, bridges, piers, seawalls, water supply systems, and, perhaps most importantly, flood insurance. The government routinely picks up all or part of the cost for most of these programs in the rest of the country, but any development on the designated barriers must take place without federal funds. On already developed barriers, the federal government continues to build and rebuild these systems as it always has.

The effects of CBRA have been difficult to ascertain. Development has proceeded in some designated areas despite the act; plans for development have been abandoned in other areas. The dividing line appears to be how far along toward development the areas were to begin with. According to Frank McGilvrey, Coastal Barriers Coordinator for the U.S. Fish and Wildlife Service, "Those areas that have infrastructure, particularly bridge and road access, are being developed, even though parts of them are in the system. We think that where those things are not in place the act will be very effective."

In April of this year, a Department of Interior

(DOI) study group released a draft report on the effects of CBRA so far and on possible modifications to make the act more effective. The draft report identifies 8 million acres of coastal barriers that might be added to the system, and also identifies a number of federal programs that indirectly subsidize development on the barriers—casualty loss deductions on taxes, for example. But public support for strengthening the act appears to be lacking. Many of the comments the DOI has received on the draft are urging the removal of areas already included in the system. "There is a lot of pressure to take areas out of the system so that they can get back on the federal dole," McGilvrey explains. Furthermore, he notes, "Developers and local governments are objecting to the expansion of the system. They're all in favor of the concept, but just take their areas out."

At public hearings on the draft report, McGilvrey has attempted to explain the problems of sea-level rise and barrier-beach dynamics in order to show why the federal government is trying to slow the development of the barriers. The result? "It's almost like they didn't hear what I said," he laments. "Their reaction is, 'We want to develop, we're entitled to develop, it's our God-given right to develop, and when we get in trouble it's the responsibility of the federal government to come in and bail us out.' No amount of trying to explain what it's all about seems to make any difference."

Maynard Silva, Research Specialist at the Marine Policy and Ocean Management Center at WHOI, blames lack of knowledge: "I think generally people don't believe in sea-level rise, or they haven't heard of it." In contrast, according to Silva, "Policymakers faced with problems of coastal erosion or barrier island retreat are aware of the problem, and view sea-level rise as making shoreline protection impossible."

This difference of opinion threatens to paralyze any concerted effort to preserve currently undeveloped barriers or to allow developed barriers to continue to retreat despite the damage that could be done to buildings and roads. But as the draft report on CBRA bluntly notes, "Coastal barriers respond to rising sea levels in one of two ways. They either continuously move landward by erosion or they drown."

Some Options

In the last few years a number of scientists, lawyers, government officials, and social scientists have begun examining ways to direct land use on barrier beaches in more environmentally sound directions and to gradually move toward restoring the beaches to free movement.

Some such policy options focus on the geological aspects of the problem. One possibility is to ban shoreline protection measures in an effort to encourage better planning before development takes place and to prevent the damage to the natural system that usually occurs from such measures. Maine has banned the building of any seawalls on sandy beaches. North Carolina is on the verge of enacting a similar measure.

Meanwhile, some coastal geologists are looking at the possibility of working with the natural processes instead of against them. Mantoloking, N.J., has put the dunes to work for it. The community has purposefully built up a 6-meter-high dune between the homes and the sea, enacted ordinances against disturbing the dune, planted beach grass, and actually built raised roads and walkways over the dune to prevent damage. During storms the dune blocks the waves, and simultaneously provides sand to nourish the beach. Godfrey helped design Mantoloking's dune-preservation program, and although he expects that rising sea level will nonetheless overwhelm the community eventually, he maintains that Mantoloking's efforts will at least "make it a little more later than sooner."

Other options are oriented toward controlling development. Barrier beaches each could be assigned a carrying capacity based on land availability, water supply, transportation and evacuation facilities, waste disposal, and recreation potential. Local plans and development regulations could then be required to take the carrying capacity of the barrier into account in deciding whether or not further development would be allowed.

Another concept being explored is transfer development rights. Under such a program, a state or local government would allow denser development or provide financial supports to developers who agree to build on the mainland instead of on beachfront property. New Jersey is negotiating with one oceanfront community to establish such a program.

Still another idea is that of rolling setbacks, also called negotiated lifetimes. Such programs, which might be incorporated into zoning laws, would restrict the right of a landowner to rebuild after storms, should the property be damaged to within a certain percentage of its value.

Similarly, development could be restricted to a certain distance behind the dune line, which would, of course, move back as the barrier retreated. There are problems with such regulations. Galveston has laws prohibiting any new construction or rebuilding forward of the farthest extent of vegetation. After hurricane Alicia, many damaged properties developed lawns in an amazingly short time.

A more extreme possibility would be for the state or federal government to acquire severely storm-damaged properties. A very limited version of such a program is now operative. Through Section 1362 of Public Law 90-448, the Federal Emergency Management Agency can attempt to arrange the purchase of severely damaged properties (at their undamaged fair market value) instead of paying to rebuild the damaged property. This program applies only to properties covered by federal flood insurance, and the owner must be willing to sell. In addition, the community in which the property is located must be willing to administer the property as open space. What limits the program most of all, however, is its annual budget of only $5 million. This budget is intended to cover not only coastal areas, but also areas subjected to flooding from inland rivers and streams. Property damage from a single hurricane

In 1984, waves crashed over these remains of a house destroyed by another storm in 1978. The land was purchased by the federal government under a pilot program of buying storm-damaged property covered by federal flood insurance rather than paying to have it rebuilt. The land is now administered by the state and the local community as public open space. Had this home been rebuilt, it might have been destroyed again last year, and the government again would have been responsible for the cost. (Photo by Jeff Benoit)

may run to billions of dollars.

If the program were expanded, it eventually would result in the government owning large portions of, and perhaps even all of, most currently developed barriers. This actually might be cheaper than repeatedly paying flood insurance benefits to the property-owners. But a bill calling for government acquisition of the undeveloped barriers was introduced during the Carter Administration, and failed to pass. According to Robert Hurley, Staff Member for the U.S. Senate Committee on Environment and Public Works, "That was clearly pie-in-the-sky and never would have happened." If the political clout to push through an acquisition program for the undeveloped barriers is lacking, it is hard to imagine that an extensive program to acquire the developed barriers (which would both cost more and probably arouse more opposition) could pass Congress.

Most of these innovative programs are a far step from reality. In much of the nation they have just begun to be discussed. In the meantime, development proceeds apace, and the problems become ever more complex.

The Role of Public Education

In Terrebonne Parish, Louisiana, local officials are particularly worried. Because of the settling of Mississippi Delta sediments on which the parish (equivalent to a county in other states) rests, relative sea level there is rising even faster than in most of the East. As a result, "Some policymakers are thinking about how in 50 years from now there won't be a Terrebonne Parish," according to Silva.

Recognizing that residents of the parish are going to face tough decisions about coastal development even sooner than most of the country, parish leaders have instituted programs in the junior high schools to educate students about coastal dynamics and sea-level rise. "Their theory," Silva explains, "is that in 10 years when they really need a lot of voter support, they'll have an educated public." Similar programs could be of great value all along the coast.

"The problem," according to Susan Halsey, "is how to translate science into something that the people can understand, deal with, accept, and then act from." This challenge faces scientists in many disciplines, but it is crucial on the coast. If action is not taken soon to change the way the coast is being developed, there will be many fewer beaches for our children and grandchildren to enjoy. Eventually, today's broad beaches might become, like the passenger pigeon of the Great Plains, an item of the past, worthy only of a paragraph or two in history books.

Frank Lowenstein is Assistant Editor at Oceanus.

Suggested readings

Barth, Michael C. and James G. Titus. 1984. *Greenhouse Effect and Sea Level Rise: A Challenge for This Generation*. New York: Van Nostrand Reinhold.

Godfrey, Paul J. 1976. Barrier beaches of the East Coast. In *Oceanus*, 19(5):27–40.

Kaufman, Wallace and Orrin H. Pilkey. 1983. *The Beaches Are Moving: The Drowning of America's Shoreline*. Durham, North Carolina: Duke University Press.

U.S. Department of the Interior. 1985. *Coastal Barrier Resources System: Draft Report to Congress*. Washington, D.C.: U.S. Department of Interior.


Tropic of Capricorn
NAUTICAL

The Underwater Bush of Australia

The Great Barrier Reef

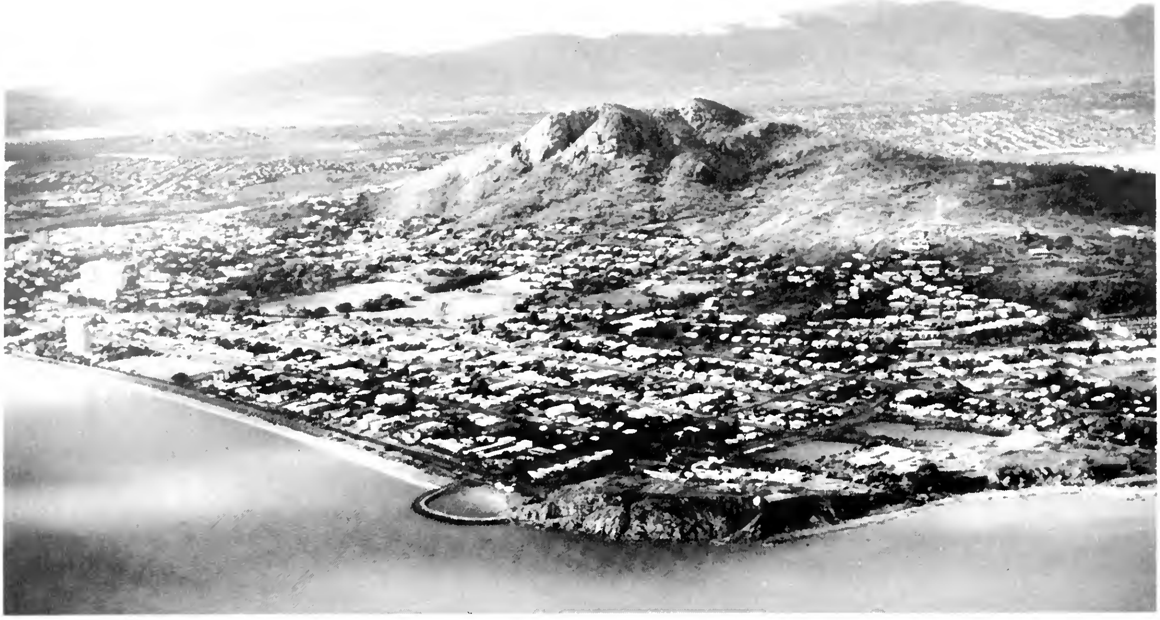
by Paul R. Ryan

In the sea sometimes you can hear the salt.
—from the Dreamtime

The underwater bush country of Australia—commonly known as the Great Barrier Reef—covers some 230,000 square kilometers of the continental shelf off the northeast coast of the continent. It is a harsh but starkly beautiful environment, similar to parts of the rural desert mainland of Australia that rests under an almost constant, searing sun. On the reef, the sun's rays penetrate into a shallow watery battleground where a large number of marine species, many dressed in subtly spectacular hues, are engaged in life-and-death struggles to establish or defend their ecological niches.

The reef itself—the outer limit of which is sometimes more than 240 kilometers offshore—extends from the Gulf of Papua in the north to south of the Tropic of Capricorn (see map on opposite page), a distance of some 2,300 kilometers. It is made up of a network of about 2,500 individual reefs, some 70 of which have

W. Saville-Kent, 1893, photographing submerged corals and bêche-de-mer.



Townsville, a city of approximately 100,000, represents a central point on the Great Barrier Reef and is home for many Australian marine scientists. (Photo courtesy GBRMPA).

formed vegetated coral cays (flat islands resting on top of coral reefs, as distinguished from high land islands).

Inside the main barrier of the reefs, where the waters are seldom more than 60 meters deep, there are an additional 540 high land islands, many with fringing reefs. Some 160 of these islands, all of which teem with beautiful tropical birds and other fauna and flora, have been set aside in whole or in part as national parks. Others have been developed into tourist resorts.

The Australian government made this vast territory a national marine park in 1975. A federal agency was set up to manage the reef and continental shelf below the low tide mark—the Great Barrier Reef Marine Park Authority (GBRMPA). The state (Queensland) is responsible for those areas above the low tide mark, except for islands or parts of islands that have been designated part of the marine park.

Graeme Kelleher, the present chairman of the GBRMPA, invited this writer to visit the reef in June and July of this year for a first-hand look at the most diverse ecosystem known to man. In the spring of 1986, *Oceanus* plans to devote an entire issue to the relatively new scientific study of the Great Barrier Reef. It promises to be an exciting issue, for the reef is not just an Australian national treasure, but a rare international jewel. Indeed, it has recently been accepted for inclusion in the World Heritage list of the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

My jumping off point for the reef was Honolulu, Hawaii, some 10 hours flying time from Woods Hole, Massachusetts. A 10-hour direct flight from Honolulu found me in Cairns, Queensland, at 6 A.M. after crossing the International Date Line and losing a day on my Timex, good to 100 meters.

Tropical terns are numerous on many Great Barrier Reef islands. (Photo courtesy GBRMPA).

Cairns is a small, sleepy resort/farm town that reminded me of similar cities along the Texas coast 20 years ago. It has a reputation for good big-game fishing, particularly giant black marlin. A 10-hour lay-over found me wandering through local shell and artifact shops, in one of which I purchased a magnificent ceremonial carved mask from the mid-Sepik region of Papua-New Guinea, a treasured addition to my modest collection. At sundown, I was finally headed for my destination, Townsville, an hour's flight over mountainous coastal terrain that afforded wondrous views of the reef, the Coral Sea, and, beyond, the South Pacific.

Townsville is a misnomer today. It is neither a town, nor a village. It is a bustling port city in the midst of growing pains. It also is the most central point on the mainland for reaching the Great Barrier Reef. Many Australian reef scientists call it home. In addition to being the headquarters of the GBRMPA, Townsville also is the home of James Cook University (JCU) with its Sir George Fisher Centre for Tropical Marine Studies (as well as several science departments with direct interest in marine research). The Australian Institute of Marine Science (AIMS) is located some 50 kilometers outside Townsville at Cape Ferguson, in an idyllic bushland setting of bounding wallabies.

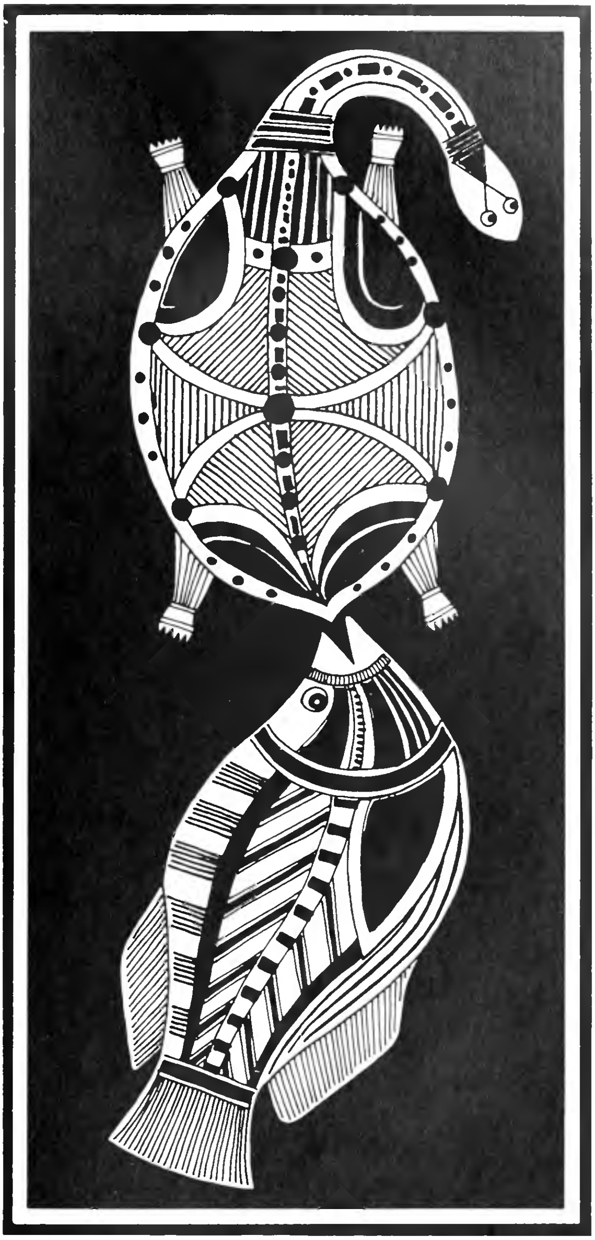
Natural and Cultural History

Geologically speaking, the Great Barrier Reef is relatively young—somewhere between 1.6 and 2 million years old. It has not grown continuously, however. During glacial periods, sea level dropped, exposing and killing the corals that form the reef. The most recent such period of depressed sea level came to an end some 15,000 years ago.

Between 15,000 and 6,000 years ago sea level rose some 45 meters to about its present level. Some 9,000 years ago, reef growth began again on the eroded remains of older reefs as they were inundated by the rising sea. This living veneer grew upward closely behind sea level. The modern reef is thus an old structure, of which living organisms form only the outermost layer.

This living layer of organisms extends from the surface down to about 40 meters under water. Below this, light from the surface is too attenuated to support the algae that are one part of the symbiotic association we call a coral. Underneath the living organisms are the calcareous remains of previous generations of corals. In a sense, the living organisms build a monument to themselves—the reef itself.

A cay will form when a reef builds up enough to be exposed at low tide and wave patterns around it cause a buildup of sediment. Seabirds deposit guano on these cays, providing fertilizer and the possibility of plant colonization by saltwater resistant seeds, which may drift to the



Art work from an aboriginal bark painting by Geri Collie.

Bush and Outback

"Bush" and "outback" are Australian terms that refer to large, sparsely populated areas of the countryside. The terms convey the notion of isolated, desolate, harsh environments in which modern man is an outsider—a nonplayer in nature's game. Man is at once awed and at the same time attracted by the beauty, complexity, and methods of survival in these environments, which the author has extended to include the Great Barrier Reef. **—PRR**

location, be blown by the wind, or be carried by birds.

Aboriginal fishermen are believed to have reached Australia between 30,000 and 40,000 years ago, long before the reef reached its present form. They probably came from somewhere in Asia in outrigger canoes capable of holding up to four persons or walked across a land bridge from New Guinea to Cape York in what is now the Torres Strait. During the modern history of the reef, they are known to have harvested shellfish, large sea turtles, and dugongs, as well as a number of different species of reef fish. The dugong, a relative of the manatee, is still harvested today by Aborigines for ritual ceremonies, comparable with our turkey at Thanksgiving and Christmas. Aboriginal rock and bark art includes numerous representations of marine species. Some 6,000 years ago, in what in the religious sphere is known as the Dreamtime or time of myth, coastal Aborigines were drawing "x-ray" art—figures of animals, reptiles, and fish that clearly show their inside anatomy, in some cases down to the details of what their stomachs hold.

The Aborigines mainly settled on the mainland while tribes of Melanesians, known today as Islanders, settled in the islands of the Great Barrier Reef. History records many battles between these early settlers.

In 1770, James Cook, the British explorer, reached the reef waters, where his ship, the *Endeavour*, ran aground. Cook claimed the Australian continent for England. A long line of explorers and scientists followed, among them Harvard's Alexander Agassiz in about 1890. In 1893, E. Saville-Kent, Commissioner for Fisheries to the Government of Queensland, published the first scientific study of the reef, entitled *The Great Barrier Reef*, along with the first black and white photographs of coral species.

Natives of Warrior Island, Torres Strait, circa 1893, preparing bêche-de-mer for the Chinese market.

Isolated coral growth on reef off Thursday Island, circa 1893. (Photo by W. Saville-Kent).

Mangroves and oysters, Endeavour Estuary, circa 1893. (Photo by W. Saville-Kent).

Some Scientific Facts

It is impossible in this article to do more than briefly introduce the scientific studies being conducted on the reef; that will be left for the March issue, which will see Michael A. Champ, presently a Senior Queens Fellow in Australia, returning by invitation as co-editor (he acted in the same capacity for our issue on the Exclusive Economic Zone [Vol. 27, No. 4]). This article, therefore, should be considered a primer for our issue on the Great Barrier Reef.

Climate. The reef has a tropical climate. It is influenced by an equatorial low pressure zone during the summer months (winter in the United States) and a sub-tropical high pressure zone during Australia's winter months. Rainfall thus occurs mostly in the summer months and is influenced by monsoons and occasional tropical cyclones. Temperatures average between 30 and 24 degrees Celsius in January and between 23 and 18 degrees Celsius in July. Wind patterns are dominated for the greater part of the year by the southeast trades, although from January to March northwesterlies prevail in the far northern section of the reef and northeasterlies elsewhere in the area.

Inside of the Great Barrier Reef is what amounts to a large lagoon with an average depth of

35 meters. Rivers flowing into the lagoon contribute significant amounts of freshwater to the system, perhaps half as much as direct rainfall. The water is vertically well-mixed for most of the year, but from January to April salinity is sharply reduced in the upper 10 meters as the result of fresh water input.

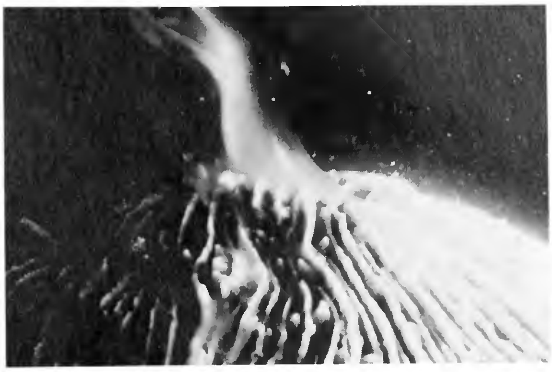
Corals and Algae. Coral polyps are closely related to jellyfish and anemones. Each coral polyp is a single organism, consisting of a cylinder of soft tissue, closed at the bottom, with a mouth surrounded by tentacles at the top. A stomach cavity occupies the center of the cylinder. Individual polyps form colonies by growth and division. Thus polyps in a colony are connected by extensions of their tissues, even of their stomach cavities.

Corals feed on planktonic organisms in the surrounding waters by paralysing their prey. They do this by firing what amounts to barbed darts from the stinging cells of their tentacles. In addition, corals derive part of their nutrition from the photosynthetic activity of single-celled plants (called zooxanthellae) contained within the coral tissue. The zooxanthellae, in turn, benefit from the association by being exposed to optimum concentrations of carbon dioxide and soluble nutrients inside the coral tissues.

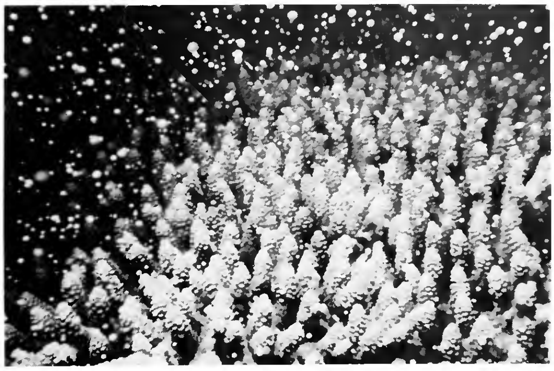
There are some 60 genera and 350 species of coral on the reef, of which the majority are *hard corals* that produce skeletons of calcium carbonate (limestone). These skeletons, together with the remains of numerous calciferous algae, form the structural basis of the reef. Thus the reef can be thought of as a sort of biological construction company. Hard corals grow in a variety of forms, including branching corals, massive corals, plate-like corals, encrusting corals, and mushroom corals.

Soft corals do not produce calcareous skeletons. Among their most interesting traits is their ability to move. They can inch up to a hard coral and do battle with it, retreating if the hard coral proves to be too much of an adversary, or advancing, killing, and overrunning the hard coral if conditions permit. They do this by releasing toxic chemicals into the seawater which accumulate in hard coral tissues, causing growth retardation and eventual death.

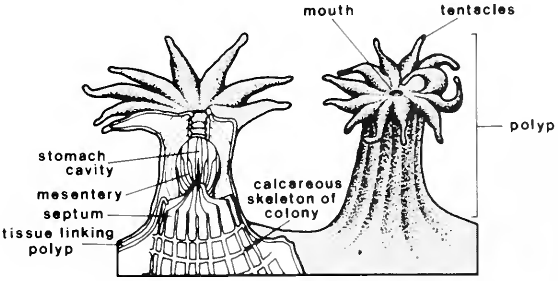
A group of graduate students in the Marine Biology Department at JCU—the Coral Reproduction Study Group—recently made a major discovery on the reef. Previously, it was generally accepted that hard corals spawn intermittently throughout the year. But the Coral Reproduction Study Group found that more than 130 species spawn just once a year, in springtime, 4 to 8 nights after a full moon. The group has captured this spectacular event on film, shown for the first time to an international congress of coral specialists in Tahiti in June. The conclusion from this work is that "synchronous spawning occurs in many corals and that the time of mass spawning is predictable." This mass spawning is one of the most spectacular events of nature, unique not only



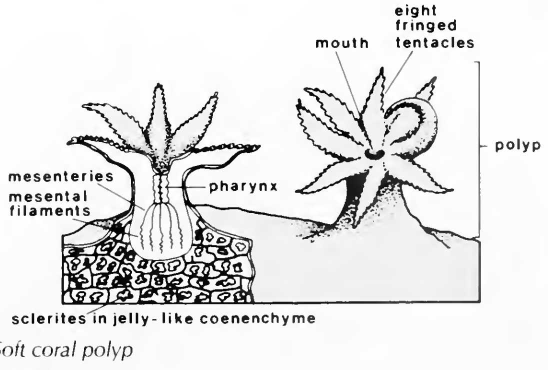
A male mushroom coral releasing sperm. (Photo by Peter Harrison)



A staghorn coral mass spawning at dusk. (Photo by Peter Harrison)



Hard coral polyp



Soft coral polyp

Some Creatures Found in

Reef trampler

Minke whale

Turtles mating

Manta ray

Sea snake

Great Barrier Reef Waters


Trail snorkelers

Photos courtesy of Great Barrier Reef Marine Park Authority


School of mostly sweetlips


Bêche-de-mer


Tiger shark


Dugong, dugong

Photo by Ben Cropp

in marine communities, but in terrestrial ones as well.

Algae, commonly known as seaweed, also play a significant role in the development of the reef. In addition to the symbiotic zooxanthellae, about 500 species of seaweed and at least 12 species of seagrass are found on the reef. Algae are classified into four phyla, named after their typical colors: brown, green, red, and blue-green. They are the primary producers of the coral reef ecosystem, supplying the food necessary for a host of organisms. The red algae are often heavily calcified—particularly the encrusting corralines—and are abundant in areas of high wave action and intense herbivore grazing activity. These algae may combine with sand and detritus off the reef to form hard deposits that add to the reef's size.

Some green algae, notably the "leafy" genus *Halimeda*, also are calcified and are responsible for producing much of the carbonate sands on coral reefs. They also produce immense, unconsolidated banks on the open continental shelf between many of the northern reefs.

Seagrasses generally form dense meadows on sandy bottoms in calm waters of the northern reef region. Some 80 to 90 percent of the plant material is below the sand in the form of roots and stems. The meadows trap organic and inorganic sediments, creating a nutrient-enriched environment for young fish and many species of fauna and flora. Few reef animals feed on living seagrasses, the most notable exceptions being dugongs, turtles, and sea urchins. Most of the energy produced by the seagrasses is passed on to other organisms through bacterial and fungal decomposition of dead plant material. Thus seagrasses act as long-term storage banks for nutrients, providing constant or seasonal releases to adjacent corals.

The Crown of Thorns Starfish. Coral colonies have several enemies, but perhaps none better known than the Crown of Thorns starfish, which when present in large numbers can devastate reefs by eating major groups of corals. The starfish is very mobile and uses suckers under its arms as tiny feet. After settling on a coral, the starfish will pull its stomach out through its mouth over the coral polyps and release digestive juices onto the coral, breaking down the polyps tissue until it can be absorbed. All that is left is the white coral skeleton, which is soon invaded by other organisms, such as worms or boring molluscs.

In recent years, scientists have observed population explosions in the number of Crown of Thorns starfish on reefs, which appear to heavily attack some reefs and not others. Just why this is so is still a mystery, although a growing number of scientists support the view that the population explosions are natural occurrences that have happened in the past as mother nature's way of maintaining high species diversity. Others have theorized that human activities, such as shell collecting or reef fishing, have reduced the number of predators on starfish eggs to the point where they no longer serve as a check on the population.

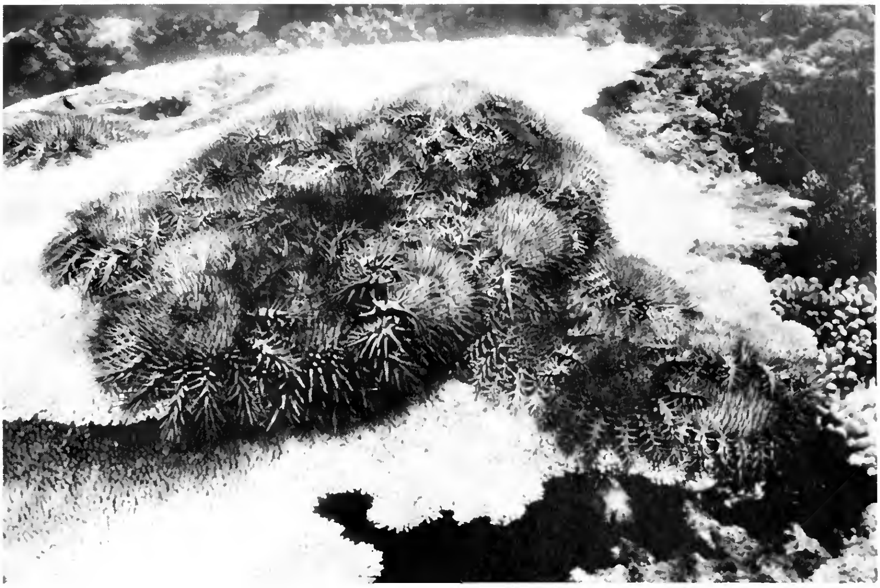
Diver injecting copper sulfate into Crown of Thorns starfish. (Photo courtesy of GBRMPA).

The Great Barrier Reef Marine Park Authority is keeping a close eye on the situation through an extensive monitoring and analysis program. In some cases, park divers working as a team inject copper sulfate into the animals with large syringes. The copper solution is toxic and serves as one method of partially controlling reef devastation; however, it can only be effective in limited areas. A diver can only inject about 150 starfish in an hour and a reef in some cases can be infested with as many as 8,000 or more starfish. Major research programs are under way aimed at learning more about the animal and its role in the ecosystem.

Fish and Mammals. There are approximately 1,500 species of fishes in reef waters and an undetermined number of marine mammals, including humpback, right, and minke whales, dolphins, and dugongs. The fishes come in a variety of sizes, shapes, colors, and behaviors—from the giant black marlin which is the game fisherman's prize to the reef grazers, such as parrotfish, surgeonfish, and coral trout (delicious broiled). Algae convert carbon dioxide dissolved in the waters into sugars and other organic materials by photosynthesis, releasing oxygen as a by-product. Grazing fish can affect the rate at which this occurs by mowing the meadows, so to speak. As grazing on seaweed and seagrasses intensifies, the rate of photosynthetic activity increases. Some grazing fish do not feed exclusively on algae but also prey on live corals, consuming both tissue and the limestone skeleton.

Manta rays are common in reef waters and divers sometimes ride them or rig tow lines to them and are pulled behind. Sharks are also found on the reef—white tip, black tip, grey, hammerhead and others—but seldom bother divers. The tiger shark is perhaps the most dangerous to man in these waters.

There is a large commercial shrimp fishery in the reef region as well as one for scallops. Mackerel, barramundi, salmon (no relation to the North American fish) and mud-crabs are also sought, as are "bugs", the Australian common name



Crown of Thorns starfish can attack corals in large numbers, causing devastating damage to a reef. Here a group has eaten a colony of plate corals. (Photo courtesy of GBRMPA).

for the slipper lobster. In addition, there is a major fishery for coral trout, sweetlips, snappers and a variety of other reef-fish species.

Clams and Other Invertebrates. More than 4,000 species of molluscs inhabit the reef waters, among them the giant clams of the family Tridacnidae. These clams, which can weigh more than 100 pounds and reach a length of several feet, were once thought to be as much as 100 years old, and a serious threat to divers. But James Cook University researchers and scientists from the Australian Institute of Marine Science have found that the clams, in fact, only live about 20 years, and that a diver can easily free himself should a clam close on him. In addition to corals, fish, and molluscs, reef fauna include foraminifera, echinoderms, crustaceans, polychaete worms, and ascidians. Many of these species penetrate and break up coral and algal structures, contributing large quantities of detritus to the reef mass. The reef supports a wide variety of echinoderms—for example, other starfish besides the crown of thorns—sea urchins, and holothurians, which are known as béche de-mer or sea slugs and also are delicious.

Managing the Reef

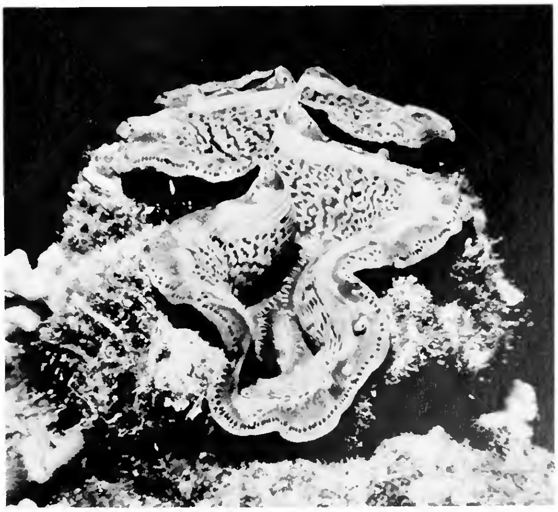
The Great Barrier Reef Marine Park Authority faces a great challenge in managing the reef. It must keep the fishermen, tourists, scientists, businessmen, and government (local, state and federal) officials happy, all at the same time. No easy task.

The reef itself is divided into five sections—the Far Northern, the Cairns and Cormorant Pass, The Central, the Capricorn, and the Capricornia. Within each section, areas are set aside by the Authority for specific uses, such as commercial and sports fishing, research, preservation and tourism. All zoning decisions made by the Authority are made with public participation. Some areas are zoned for multi-purpose uses.

A marine scientist, Donald W. Kinsey, acts as Executive Officer of the Authority. An ecologist, Kinsey was Assistant Director of the Australian Institute of Marine Science before coming to GBRMPA. He also has served as Director of the marine lab at Sapelo Island, run by the University of Georgia, a U.S. lab that has produced a number of eminent ecologists.

The Authority is presently coordinating the building of a large aquarium complex in Townsville as a bicentennial project. Called Reef Wonderland, the town project is scheduled to be completed in 1988.

In addition to the aquarium, which will have



Research on the giant clam, shown here in its natural habitat, is revising many theories about this animal. (Photo courtesy of GBRMPA).

Doug Tarca with a model of his reef hotel, presently under construction.

a large, functioning coral reef system, there will be a museum, an Omnimax Theatre, which will give the audience the illusion of being under water amid coral reefs, and an arcade of tourist shops. The complex also will include new offices for GBRMPA.

The aquarium complex will be located at a harbor site, a short walk from the center of town. It is envisioned that the aquarium will create a demand by visitors to go out on the reef. There is now in operation a catamaran ferry called Reef Link that takes 100 passengers out to John Brewer Reef for a day of snorkelling or scuba diving. For $A60, the passenger gets lunch, diving gear, and a ride in Doug Tarca's yellow submarine, a semi-submersible bus that allows 50 people at a time to partake of a once-in-a-lifetime view of the reef. Tarca, Managing Director of Reef Link, is building two more catamarans and a floating hotel in anticipation of increased business generated by the aquarium complex and a Sheraton casino-hotel that will be operational in Townsville by 1986. Tarca's Reef Hotel will be the first of its kind in Australian waters with 200 units, 3 bars, and a restaurant. It will be accessible by seaplane, private boat, and catamaran ferry.

The Authority believes that eventually as many as 500,000 people may visit the aquarium in a single year. If this becomes reality, Townsville, now a city of approximately 100,000, will change. More hotels will have to be built, more parking space sought, more roads paved, the airport expanded, and so on. The reef will change, too, as the result of the increased presence of man. At present, there is little apparent pollution in reef waters, but a major oil spill could prove catastrophic. The Authority will certainly have its hands full in managing this increased activity.

Research Labs and Programs

There are four research labs out on the reef run by various institutions: one at Orpheus Island (James Cook University), Heron Island (Queensland University), Lizard Island (The Australian Museum) and One Tree Island (Sydney University). Scientists can rent bench space and facilities at these labs very reasonably.

On the mainland, the Australian Institute of Marine Science at Cape Ferguson is at this writing under the leadership of John S. Bunt, who will step down in late August of this year after 7 years as Director. The Institute has five main research program/areas: mangroves, the nearshore environment, reef metabolism, reef ecology, and shelf seas.

The mangrove program is developing a comprehensive description of the present state of Australia's mangrove communities. This includes descriptions of geographical variations in structure, distribution, plant phenology and primary production. In addition, the program is looking at factors such as latitude, macro-climatic features, topography, salinity regime, and soil chemistry. Another area is whether mangroves are similar to salt marshes in function, contributing nutrients to nearshore reef areas.

The nearshore program is concerned with developing an understanding of productivity, trophic enhancement, recycling and remineralization, and physical mixing and redistribution in the context of fluvial and wetland outwelling.

The reef metabolism program is aimed at answering a number of major questions, among them: how does organic carbon reach and become available to consumers? How do coral reefs satisfy their inorganic nutrient requirements and to what extent are primary production and calcification

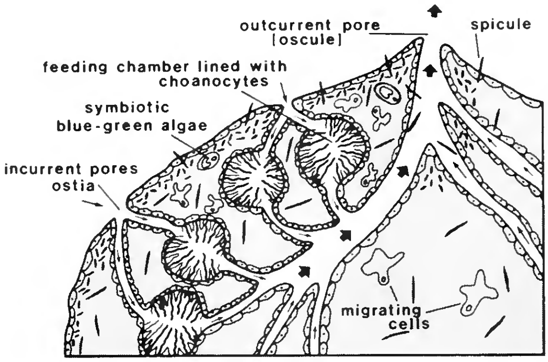
Artist rendition of what Reef Wonderland aquarium will look like, scheduled to open in 1988. (Artwork courtesy of GBRMPA).

"Vacuum Cleaning" on the Reef

When most of us think of a sponge—the image is probably associated with the bathroom, kitchen, or someone we know. The household sponge, however, is just one type of skeleton of several sponge species among thousands that live in the sea.

The sponge's role in laying down new limestone for coral reef growth is a minor one on the modern reef, but nevertheless an important part of the complex structural process. Boring sponges, relatively small in number in terms of species, chemically digest the limestone skeletons of corals during their search for living space and possibly food. When they bore into the coral, they dissolve about 10 percent of the skeleton. The tiny chips are expelled into the water and constitute a sizable portion of the fine sediments that settle into holes in the reef structure or down on the bottom of reef lagoons.

Sponges have been called the most efficient "vacuum cleaners" in the sea. They can remove tiny food particles from surrounding waters, such as bacteria, detritus, and coral mucus.



Sponges can filter their own volume of water every 4 to 20 seconds. A baseball-sized sponge will pump about 5,000 liters of water through its body in a day.

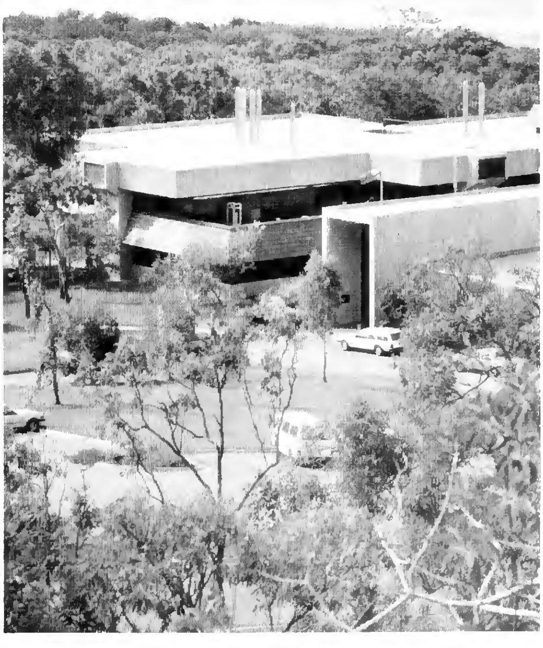
Sponges are found in the fossil record as far back as the Precambrian (650 million years ago). They may have been the first multi-cellular animals. **—PRR**

limited by nutrient supply? What are the regulating mechanisms governing calcification on coral reefs?

The major objective of the *reef ecology* group is to detect patterns in the distribution and abundance of reef communities in space and time, converting these studies into models of system structure and dynamics.

The *shelf seas program* is testing the theory that a significant part of the heterogeneity of Great Barrier Reef ecosystems is influenced by spatially and temporally varying intrusions of nutrient-rich waters from land runoff and shelf upwelling.

One of the main thrusts of the Sir George Fisher Centre for Tropical Marine Studies at James Cook University is a search for organisms that may be of use in medical and commercial research. Several exotic and toxic marine organisms give promise. Joe T. Baker, Director of the Centre at this writing, has contributed greatly to its development and high level of research. He has been nominated to become the next director of the Australian Institute of Marine Science. Several departments in the University are engaged in marine research, among them the engineering faculty under Professor Kevin Stark, which has a novel program for stress testing buildings under typhoon and



The Australian Institute of Marine Science at Cape Ferguson. (Photo courtesy of the Institute)

Beware the Box Jellyfish

The most dangerous animal to humans in Great Barrier Reef waters is not the shark, but the box jellyfish, Chironex fleckeri. *It accounts for an average of three deaths a year in Australia.*

The box jellyfish, so named because of its cube-shaped body, is the world's only known stinging coelenterate lethal to man. There have been more than 60 confirmed deaths in Australia as the result of stings from this animal, more than half in reef waters, since records have been kept. Many of the victims have been children. In a third of the fatal cases, death came within 3 minutes or less of the sting. It is estimated that there have been many more unconfirmed deaths as the result of stings by this animal.

Given time and opportunity, the box jellyfish will avoid human contact, but it can move only about as fast as a man can walk. Contact usually occurs because a swimmer blunders into its tentacles.

Other invertebrates of a venomous nature on the reef include all the true jellyfish, such as the blubber jellyfish, hair jelly, and little mauve stinger, and some planktonic medusae; in addition, certain sea anemones and corals, cone shells, and octopus.

In the vertebrate category, almost all marine fish species appear capable of causing tropical fish poisoning (Ciguatera) if eaten. Also reef and estuarine stonefish are poisonous if stepped on, as are stingrays. Snakes, of course, including the yellow-bellied sea snake, are venomous, and should be avoided by divers.

—PRR

The prawn fishing fleet tied up in Townsville. (Photo courtesy of GBRMPA).

hurricane conditions. They actually build a building (often donated by contractors), and then subject it to measured stress until it tears apart.

The Future

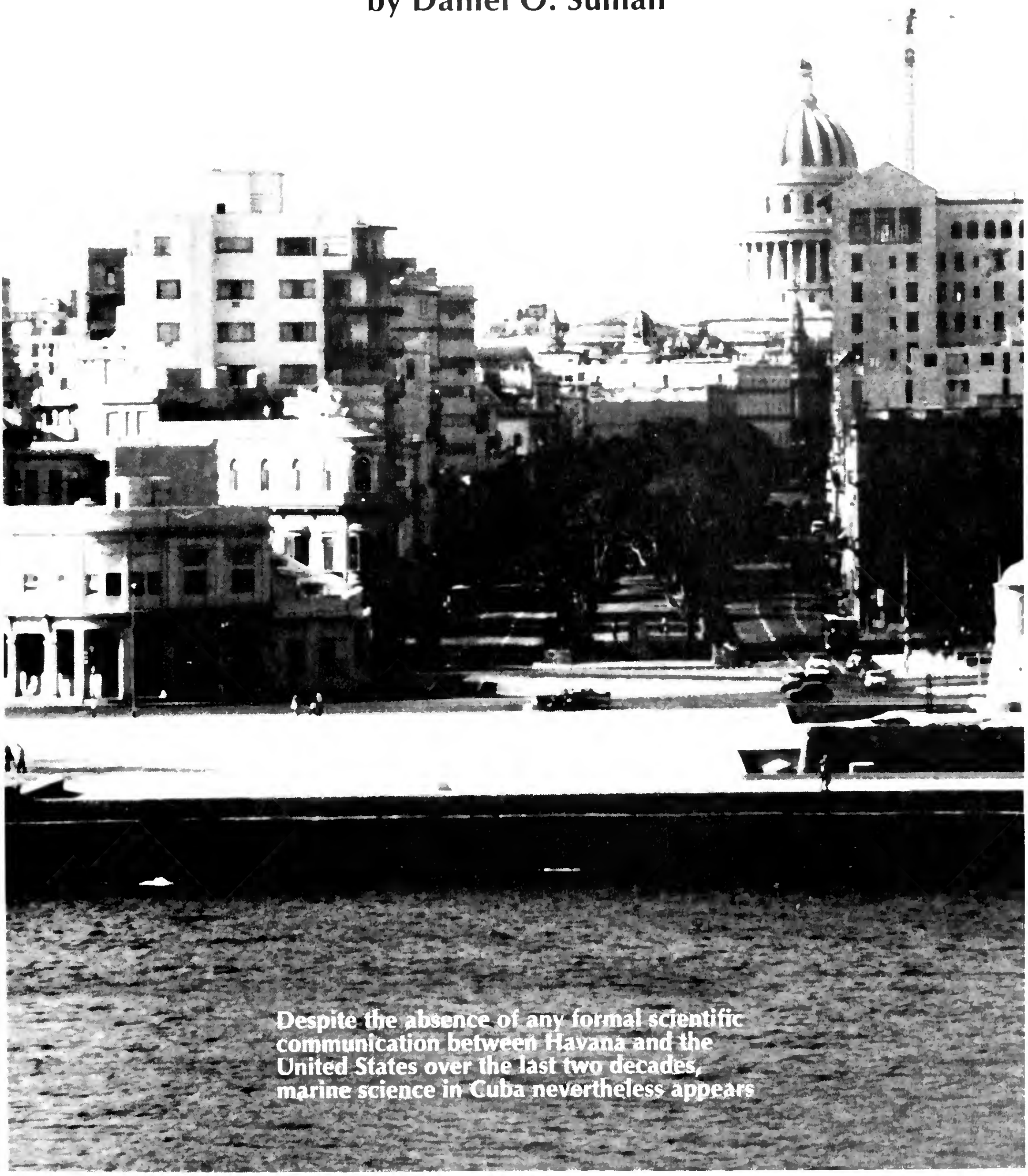
Modern large-scale scientific research on the reef will be the next step. Many early theories about the development of coral reefs most probably will be revised in the near future. The work of scientists in and around Townsville will be at the center of this change as researchers seek to answer just why their underwater outback—the Great Barrier Reef—has been blessed with the most diverse, if harsh and spectacularly beautiful, ecosystem known to man.

Paul R. Ryan is Editor of Oceanus *magazine at the Woods Hole Oceanographic Institution.*

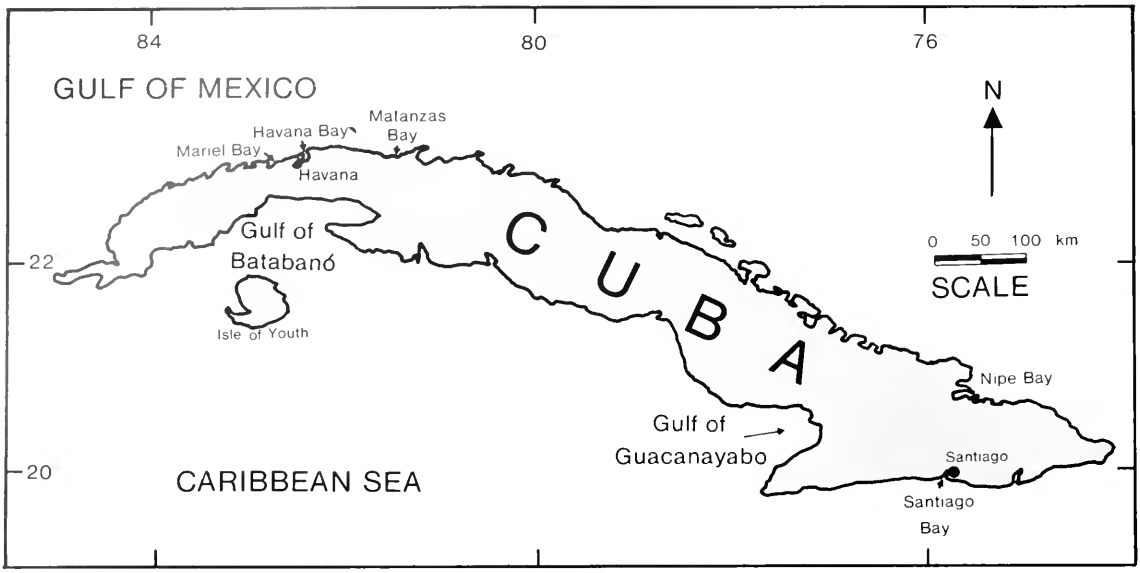
Giant black marlin are a favorite game fish in Great Barrier Reef waters. (Photo courtesy of GBRMPA).

Marine Science in Cuba

by Daniel O. Suman



Above, the City of Havana. The old capitol dome in the background is a two-thirds replica of the U.S. capitol dome in Washington. The Havana building is the new headquarters of the Cuban Academy of Sciences. (Photo by Katherine S. Orr and Carl J. Berg)



to have made significant progress during this period. In the areas of fisheries development, coastal resource management, and marine pollution, Cuban science is on a par with research done in much larger Latin American countries. I reached these conclusions recently after participating in a 3-day Marine Science Symposium at the Cuban Institute of Oceanology.

This visitor was struck by the relative youth of most researchers in the marine sciences in Cuba. For the most part, they are under the age of 40. Indeed, prior to the revolution that culminated in 1959 with the overthrow of Fulgencio Batista by Fidel Castro, oceanography in Cuba did not exist as an academic endeavor. In 1965, the Institute of Oceanology was established as one of 22 research institutes of the newly reorganized Cuban Academy of Sciences. Today, about 2 percent of the national budget is allocated to research in science and technology. No figure was available for the amount or percentage of this allocated to marine science.

Marine research in Cuba is heavily oriented toward fisheries studies because of the industry's economic importance to the nation. Cuba's fish catch in 1984 was more than 200,000 metric tons compared with 27,000 metric tons in 1959. In the early 1960s, the Ministry of Fisheries established its first two fleets—the Gulf Fleet (Gulf of Mexico) and the Cuban Fishing Fleet (operating in the Atlantic and Pacific Oceans).

It is not surprising then that marine biology is a particularly strong discipline in Cuba. Cubans appear to be as advanced as their counterparts in Mexico, Brazil, and Argentina, nations with a much older scientific tradition.

In addition to the Institute of Oceanology, there are numerous other organizations in Cuba that perform research in the marine sciences. I have mentioned the Ministry of Fisheries, which funds research centers concerned with aquaculture, naval architecture, and fish processing, as well as direct fisheries studies. The University of Havana has a Center for Marine Research (mostly engaged in biological studies), and the Ministry of Transportation through its Transport Research Institute has conducted several marine pollution studies. Many projects are collaborative ventures, with extensive cooperation occurring between research centers.

The Institute of Oceanology

The Cuban Academy of Sciences' Institute of Oceanology is celebrating its 20th anniversary this year. The three original departments of plankton, benthos, and ichthyology have been joined by chemical oceanography, physical oceanography, and marine geology. Thirty-nine senior investigators and 64 technicians work in these departments. Some 400 studies have been published to date under Institute auspices as well as more than 260 articles by Institute researchers.

The Institute's laboratories and offices are located in the western suburbs of Havana. It has access to several research vessels and scuba facilities through the Academy's Department of Nautical Activities and Aquatic Services. Cruises are generally limited to Cuba's coastal zone. The length of its largest vessel is 20 meters.

During the last two decades, the Department of Plankton and Primary Productivity has studied the composition and distribution of plankton in the waters of the Cuban continental shelf and the Gulf of Mexico. The larval stages of economically important species of lobster, tuna, and groupers also have been studied.

The Department of Benthos has categorized the benthic infauna on the Cuban continental shelf with respect to density, biomass, and composition. The community structures of different biotopes (coral reefs, seagrasses, mangroves, sandy sediments) also have been studied. Over the years, this group has evaluated benthic organisms, such as sponges and gorgonians, for their pharmacological

El Morro fort guards the entrance to Havana Harbor with the skyline of the city in the background. (Photo by author)

promise. Several researchers are actively involved with conch (*Strombus gigas*) biology. Their work has resulted in the increasing regulation of this fishery and the beginning of conch mariculture. The benthos specialists also have completed several studies on environmental degradation in highly polluted areas, such as Havana Bay. They also have searched for benthic organisms that could serve as indicators of pollutants. In addition, they are preparing a book on Cuban corals that is targeted toward a non-specialized audience.

The Department of Ichthyology has programs under way in taxonomy, fisheries biology, physiology of commercial species, fish parasitology, and, most recently, mariculture. Taxonomical information has been summarized in a four-volume *Sinopsis de los Peces Marinos de Cuba* (Synopsis of Marine Fish of Cuba), published by the Institute. The behavior, ecology, and life cycles of the 10 most economically important fish species in Cuban waters also have been published. In addition, the department has prepared guidelines for pond cultivation of grey mullet. Fish ecology and behavior around artificial reefs and shelters is a new research interest.

The Department of Chemical Oceanography and the adjunct Laboratory of Chemical Analysis are at the service of researchers in other departments who desire standard water analyses. The department also carries on an active program in the hydrochemistry of the continental shelf and pollution monitoring in bays and estuaries.

The Marine Geology Department has conducted studies of the mineralogy, geomorphology, and sedimentology of the continental shelf. Estuaries, such as those in Havana, Mariel, Matanzas, and Santiago have been extensively studied. This department is interested in shore processes and is often consulted by other governmental organizations before construction of port facilities is begun.

From 1968 to 1982, the Physical Oceanography Department established and monitored a national series of tidal stations. It published Cuban tidal data until 1982, when the Tidal Services Laboratory was established outside the department. Although the department is interested in currents in the waters over the continental shelf, most of its emphasis has been on the hydrology of select, economically important gulfs and bays.

The Microbiology Laboratory is an independent group at the Institute that investigates marine yeasts and bacteria. The group monitors bacterial levels at Cuban beaches and has studied Havana and Santiago Bays. New research interests involve bacteria that degrade petroleum products.

Certain priority research areas cut across departments. For example, all departments are involved in research in the Gulf of Batabanó, the wide, shallow shelf on the southwestern coast of Cuba between the main island and the Isle of Youth. The Gulf is Cuba's most productive lobster ground and is also an important fishing zone. Another region often studied is the Gulf of Guacanayabo, an important area for shrimp trawling off southeast Cuba. Similarly, all departments are studying Havana Bay, which is heavily polluted, and are tracking areas less seriously contaminated, such as Santiago and Nipe Bays in the east.

Centralized planning makes such institute-wide research possible. For example, when the government's planning institutions have delineated the "Principal State Problems," they may approach the Academy of Sciences and request a study that could possibly solve the problem. If the Institute of Oceanology is chosen as the appropriate body, its

Outside the lounge at the Institute of Oceanology, the sign reads, "Nothing is more marvelous in the universe than the ocean." The saying is by Jose Marti, a national hero. (Photo by Katherine S. Orr and Carl J. Berg)

scientists define the specific study they will undertake. The Academy itself may also identify a research priority.

About 50 percent of all research projects, however, are initiated by individual researchers. Regardless of the level of project initiation, the research plan must first be approved first by one's department companions, and then by the Institute's Scientific Council. Each scientist is responsible for his or her research design, but the project must meet national needs. The results of research projects are rarely published in international journals.

Carl Berg of the Marine Biological Laboratory at Woods Hole, Massachusetts, discussing his research with Cuban icthyologist Georgina Bustamante at Symposium on Marine Science. (Photo by Katherine S. Orr)

In 1966, the Institute published its first journal, *Estudios*, which was discontinued after three issues. By and large, the articles reported the results of the joint Cuban/Soviet expeditions in the Gulf of Mexico and the Caribbean in 1964-65.

Serie Oceanológica followed with 36 issues from 1968-76. About 80 percent of these publications concerned studies of benthos, plankton, or ichthyology. Many had joint Cuban/Soviet authorship. From 1977-81, oceanographic manuscripts were published by the Academy in three journals (*Informe Científico-Técnico, Ciencias Biológicas*, and *Ciencias de la Tierra y del Espacio*). The Institute of Oceanology has edited *Reporte de Investigación* since 1980 and hopes to begin publishing a new marine science journal, which will span all marine fields. The quality of the reports, the strictly Cuban authorship, and the wide range of topics indicate that Cuba is taking marine science seriously.

Certainly, the absence of scientific communication with the United States has hurt Cuban marine science. U.S. scientific journals and books are difficult to obtain. At the same time, the Institute maintains publication exchanges and collaborative agreements with 245 marine science institutions around the world.

The Center for Marine Research

The Center for Marine Research (CIM) is the marine biology station of the Biology Faculty at the University of Havana. Some 20 researchers work at CIM's main laboratory in Miramar, Havana, combining their research with teaching responsibilities and thesis advising. CIM's students have all completed five years of general biology studies at the University of Havana and spend an additional year specializing in marine biology. Many students carry out their research in collaboration with the Institute of Oceanology.

The Institute of Oceanology's main laboratories are located on the beach in the suburbs of western Havana. (Photo by author)

Research projects at the CIM are oriented toward economically valuable marine species. Studies center around shrimp and lobster physiology, aquaculture, marine botany, coastal lagoon ecology, phytoplankton distribution, and benthic ecology.

CIM began publishing in 1972 through the University of Havana's journal, *Ciencias (Serie 8, Investigaciones Marinas)*. Forty-six issues were published in this series before CIM began its own journal (*Revista de Ciencias Marinas*) in 1980. Six volumes of this journal have been printed to date.

Transport Research Institute

The Transport Research Insitute (IIT) is the branch of the Ministry of Transport that is responsible for monitoring pollution problems in Cuban ports. A staff of about 60 work in the main laboratories, located in Casablanca on the eastern shore of Havana Bay. The group is equipped to study currents and hydrology, sedimentology, hydrochemistry, microbiology, and benthic ecology. The Institute has the capability of measuring hydrocarbons, pesticides, and heavy metals in waters and sediments. It has chosen the sea urchin as the animal to monitor contaminants. Computer facilities are available for data analysis.

A significant part of IIT's research efforts has been directed toward Havana Bay, the country's largest port facility. Funds were obtained from the United Nations Development Program (UNDP) for a recently completed four-year study of the Bay's pollution problems. Not only is Havana Bay one of the world's most polluted waters, it probably has been studied more than any other bay in the Caribbean.

The bay is 5.1 square kilometers in area. Havana, a city of two million people, sits on its shore. Not only are major port facilities located around the bay, but Cuba's largest petroleum refinery, a large thermoelectric plant, fertilizer plants, distilleries, and slaughterhouses surround the bay. The annual flux of hydrocarbons to the bay was recently estimated at more than 5,000 metric tons, which is the capacity of a small tanker. Concentrations of hydrocarbons in the sediments reach 1.42 percent.

The most serious problem, however, is one of untreated sewage entering the bay through storm drains, some of which date back to the colonial era. A daily volume of 270,000 cubic meters of sewage enters the bay which itself has a volume of 47,000,000 cubic meters. If the surface layer with its metallic-grey color caused by the petroleum pollution could be removed, the waters would be bright green, because of eutrophication.

Physical oceanographers at IIT have calculated a renewal time of 12 days for waters in the bay, if all pollution were to stop. IIT has recommended that certain industries be transferred away from the bay and urban areas. Moreover, it has recommended that a number of sewage-treatment plants should be built for the city, with all operational by the year 2000.

The Ministry of Fisheries

The Ministry of Fisheries (MIP) coordinates 40 enterprises involved in the capture and distribution of fish. It also oversees the maintenance of Cuba's fishing boats, which number more than 2,000. Some 39,000 workers are employed in fisheries, including 17,000 fishermen.

In 1959, fisheries were largely artisanal and limited by problems of underdevelopment. A marketing infrastructure did not exist. Fish were only sold at ports or in the provincial capitals.

Since 1959, modern boats have been constructed, port facilities improved, and freezers and market networks established. The total catch for 1984 was more than 200,000 metic tons, about

Havana Bay is highly polluted by petroleum, industrial wastes, and untreated sewage. (Photo by author)

10 times that of 1959. Of this amount, about half was consumed nationally and half exported.

Cuba's fishing fleets have become specialized. The Cuban Fishing Fleet, founded in 1962, now produces about half of the total catch. Its 26 sophisticated supertrawlers are floating factories that operate throughout the Atlantic and Pacific Oceans. The Cuban Tuna Fleet, based in Havana and the Canary Islands, consists of 20 long-line boats, which operate primarily in the central Atlantic. The Continental Shelf Fleet plies Cuba's 200-mile Exclusive Economic Zone, producing 37 percent of the catch. Lobster and shrimp are the most valuable commodities in the catch.

The considerable growth in fisheries during the last two decades has been sustained by the support given to marine research and development. More than 270 senior investigators work in the Ministry of Fisheries research centers in shelf fisheries, aquaculture, naval architecture, and fish processing and products.

Fisheries biologists at the Fisheries Research Center (CIP) study plankton distributions, fisheries dynamics and populations, effective capture methods, fish physiology, and management and preservation of marine resources. The Center's sporadic publications have included *CIP Contribuciones* and *Resumen de Investigaciones, (CIP)*.

The Center for Naval Products and Technology (CEPRONA) was founded in 1977 to develop and design new ship models and improve fishing gear. CEPRONA has designed more than 100 models of ferrocement, plastic, and steel boats. This has stimulated the construction of more than 1,000 ferrocement vessels, making Cuba a world leader in this area.

The 53 researchers at the Center for Technological Research in the Fishing Industry (CITIP) work in the areas of quality control, the development of new marine products, and the utilization of new species. Recent efforts have focused on products from freshwater species and utilization of the shrimp by-catch. Some 43 new products are now distributed, thanks to CITIP's efforts.

Created in 1980, the National Aquaculture Enterprise (ENACUI) reported a catch of 17,000 metric tons in 1984. Six hatcheries produce tilapia, carp, tench, mullet, and catfish fingerlings and shrimp larvae. ENACUI research is directed toward the biotechniques of breeding and hatchery production, parasitology, artificial diets, and fisheries management in reservoirs.

Obstacles to Progress

While marine science in Cuba has made substantial progress, it does face problems. Many of these are common to all scientific establishments in Latin America and the Third World: shortage of funds, equipment, and research personnel, as well as the absence of a scientific tradition.

Although Cuba has done much to overcome these obstacles, it is still confronted with one major handicap, an economic and scientific blockade by the United States. Communication between marine scientists from Cuba and the United States is virtually nonexistent. Large areas of the Caribbean, unknown to American oceanographers, have been widely investigated by the Cubans, for example, biological distributions of echinoderms, mollusks, decapod crustaceans, algae, and sponges in the Gulf of Batabanó. On the other hand, important oceanographic books and journals published in the United States are absent from Cuban research libraries. Moreover, Gulf and Caribbean research performed by each country is not shared. The economic blockade, forcing Cuba to purchase scientific reagents and equipment from European countries, results in high transportation costs. And, in a country where funds are limited, this curtails research.

Cuban marine scientists, although they tend to publish more than their Latin American colleagues, focus on their own journals, rather than the international journals with wider circulation. Cuban oceanographers suggest that this is necessary to transmit the information for Cuba's economic development. For those who wish to share ideas with a wider audience, the blockade disrupts possibilities for normal scientific discourse through the mails. Dollars for page charges are out of the question. The difficulty of writing in a foreign language further compounds this scientific isolationism.

Cuban marine biologists enjoy lunch hour at the Institute of Oceanology. (Photo by author)

Conclusions

Marine science in Cuba has made great strides as a result of the tremendous scientific explosion that has occurred in the last two decades. The relation between production and research is close. Research priorities are determined nationally with input from the scientists themselves as well as from the productive sectors and political entities. These serve as guidelines for research at all levels. Priorities in marine research have been fisheries development, coastal resource management, and marine pollution. In these areas, Cuban marine science is on a par with research in larger Latin American countries.

Cuban marine science will become increasingly visible in the Caribbean and Latin America. Cuba will deepen its cooperation with marine scientists from Mexico, Venezuela, Colombia, and Panama, who also are studying Caribbean phenomena. A major international oceanographic conference is scheduled for 1987 in Havana. The Institute of Oceanology hopes to begin an international marine science journal that will lead to improved scientific exchange throughout the Caribbean. These regional efforts should launch the normalization and unity in the Americas needed for scientific advancement.

Daniel Suman is a chemical oceanographer. He is presently a research fellow at the Board on Science and Technology for International Development of the National Academy of Sciences, Washington, D.C.

Marine scientists interested in contacting Cuban research centers can write to the following addresses:

Centro de Investigaciones Marinas (CIM)
Universidad de la Habana
Avenida 1ra, No. 2808, Miramar
La Habana, Cuba

Centro de Investigaciones Pesqueras (CIP)
Ministerio de la Industria Pesquera
Avenida 1ra y 26, Miramar
La Habana, Cuba

Departamento de Contaminación
Instituto de Investigaciones del Transporte (IIT)
Apartado 17029, Zona Postal 17
Casablanca, Ciudad Habana
Cuba

Instituto de Oceanología
Academia de Ciencias de Cuba
Avenida 1ra, No. 18406, Playa
La Habana, Cuba

References

Academia de Ciencias de Cuba. 1985. *Memoria - XX Aniversario del Instituto de Oceanología*, Havana.
de la Cruz, Alfredo, and Sylvia Leal. 1982. Segunda adición a la bibliografía de los recursos marinos y fluviátiles de Cuba. *Rev. de Investig. Mar.* III(2).
González, Jorge Julio. 1985. En la recta final del quinquenio, *Mar y Pesca* 233:14-18.
Instituto de Investigaciones del Transporte, Ministerio del Transporte. 1984. *Investigación y Control de la Contaminación Marina en la Bahía de la Habana*, Havana.
Morales, Pedro. 1984. El salto hacia los caladeros internacionales. *Mar y Pesca* 227:8-11.

CAMS—A Think Tank for Global Ocean Problems

By Victoria A. Kaharl

> *"The ocean is not a series of separate compartments of physics, chemistry, biology . . . Everything is intermeshed in a very important way. It's like a rug with a very intricate pattern."*
> **—William Jenkins, WHOI geochemist**
>
> *"The ocean scientist today must reach out and join forces with others of complimentary expertise in order to address the critical global problems which can no longer be solved by single individuals or single disciplines."*
> **—Peter Wiebe, CAMS director**

In 1981, the Center for the Analysis of Marine Systems (CAMS), also called by some the "Center for Awfully Marvelous Stuff," was established on Cape Cod at the Woods Hole Oceanographic Institution (WHOI). An international research center, CAMS was created as an interdisciplinary "think tank" to meet several needs of modern oceanography—the need for more theoretical studies and numerical modelling; for cross-disciplinary collaboration; and for a haven, like a halfway house on a long desert road, that would give new ideas, too risky or too interdisciplinary for the traditional funding agencies, a chance to take root.

Located on the second floor of Fenno House on WHOI's Quissett campus, CAMS is supported by private sources, which have included large philanthropic foundations and an anonymous donor. Since its founding, CAMS has received a total of about $750,000—a modest amount that has been spent for the most part on computer time for numerical modelling, honoraria and travelling expenses for guest speakers, coffee and donuts for the Center's seminars, and research projects.

A CAMS project usually begins with an idea for a topic or a conference or series of informal lectures that may stretch out over six months. Although anyone may suggest topics, the subject matter must pass the muster of an eight-member advisory committee and the CAMS Director, Peter Weibe, a biological oceanographer. Wiebe is responsible to the WHOI administration and its Staff Council, comprising the five department chairmen.

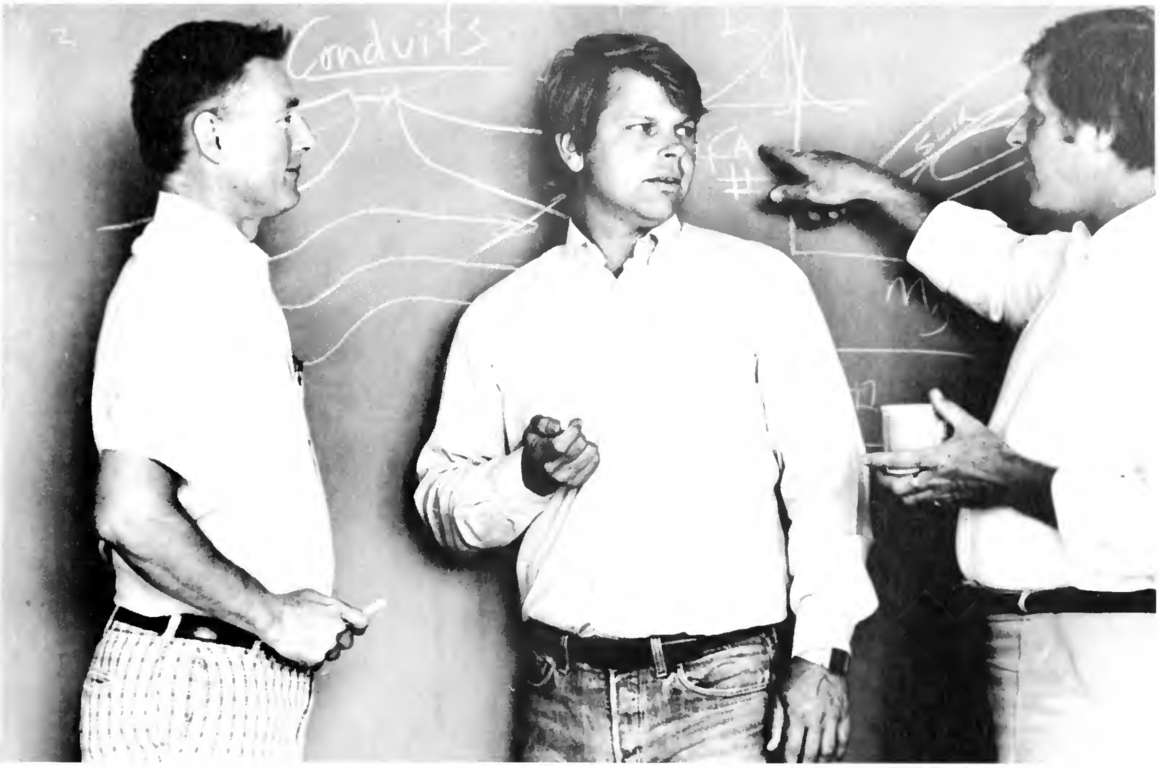
Some scholars are invited to conduct work at the Center for anywhere from 6 to 18 months before returning to their respective departments at WHOI or their work places far from Woods Hole. More typically, invitations to lectures are sent to scientists of various backgrounds and disciplines, but with common research interests.

For some, the interdisciplinary collaboration leads to work for the first time with scientists of different disciplines and data from outside their field. That is the "marvelous stuff" some CAMS participants only half jokingly use for the M and S in the Center's acronym.

No project is meant to be permanent. Rather, the Center acts as a catalyst. Ideas for research are born and then worked on with the tools of modelling and theory. Once a project can stand on its own, investigators seek the necessary support from the traditional funding agencies, such as the National Science Foundation or the Office of Naval Research.

Group brain-storming has earned CAMS the sobriquet of Think Tank. But the nickname, to some CAMS alumni, does not reflect fully the Center's openness and special style—its knack for mixing fisheries managers with physicists; its eagerness to embrace any good idea and allow anyone to attend lectures and conferences. "Think Tank implies isolation and a feeling of superiority," says Peter Rhines, CAMS's first director and a physical oceanographer now at the University of Washington in Seattle. "If anything characterizes CAMS it *is* ideas and CAMS *is* a place where you think, but the people who are doing the thinking are streaming in and out from the real world. It's not elitist. In the past, the theoreticians had good reason to be isolated; they had nothing to say to the observationists. CAMS is not a group of isolated theoreticians. CAMS is theory, observation, and computer modelling. All three elements reverberating together. It is an enormously rich mixture."

Our world, it seems, has come to demand such a mixture in an interdisciplinary framework. Oceanographers are facing more and more questions that cannot be answered through the understanding of a single scientific discipline using the traditional tools of the naturalist. The more mankind's activities affect the marine environment, the more urgent the quest for the answers to those questions becomes.



CAMS investigators discussing geophysical problem. (Photo by Suki Coughlin)

Growing pressure to use the oceans for waste disposal, for example, has created an urgency to define where pollutants travel in the ocean, how quickly they spread or dilute. Hundreds of thousands of tons of waste—both toxic and nuclear—already have found their way into the oceans. We know some of their short-term effects on marine life, but not their long-term consequences. The path a pollutant takes in the ocean involves chemical, biological, physical and geological factors. Depending on the pollutant's composition, it may interact with marine plants and animals, the atmosphere, ocean sediment, and the water itself. Its path is affected by the physics of ocean circulation, including the planetary forces of the Earth's rotation and the tide-causing pull of the sun and moon. The geological features of the ocean bottom affect a pollutant's migration. And to further complicate our attempts to follow the pollutant, the ocean is a single entity that stretches in one vast expanse around the globe. Everywhere its waters mingle and circulate, horizontally and vertically, at all levels, in different directions, at different speeds.

Single Discipline Approach

The traditional research structure is not geared to interdisciplinary research. Oceanographers of different disciplines do not usually work together; funding agencies tend to reinforce this by approving projects that usually involve a single discipline. The more specialized scientists become, the less able they are to communicate with scientists outside their discipline, and the less they know about matters outside their specialty.

"There's a very strong tendency in any building, in any field for people to set themselves up in little cubicles and communicate only with those people, usually very specialized, that they have to talk to," says William Jenkins, a geochemist at WHOI and a CAMS investigator. "There's always very strong pressure in the field to specialize, to know more and more about less and less. It's a natural defense because the problems become extremely complicated and sophisticated. You get forced into the mode of looking at the trees rather than the forest."

Jenkins's analogy is especially appropriate. To solve some of the major problems in the marine environment, oceanographers are looking at the proverbial forest. They have begun to perceive land, ocean, and atmosphere not as three separate systems, but as one grand symphony of many well-tuned components that together combine to make infinitely intricate music—all within the score of a single composition. In this global, encompassing view, the ocean is the flywheel that stores much of the Earth's energy and drives not just the marine environment, but the atmosphere as well. And both exert powerful influences on the land.

The complexity of this marine world seems infinite. Without computers, much of it would be beyond exploration. CAMS provides access to computers, including the fastest and most powerful available, the "supercomputers." By solving differential equations on computers, scientists can simulate processes that take place in the marine environment. They can trace, for instance, a pollutant's possible path. Supercomputers, because of their great speed and power, are becoming the test tracks, the wind tunnels and the oceanographic laboratories of the future.

Rather than go into the field for data, CAMS investigators use information already on hand. This may include huge amounts of data that have not been fully analyzed or looked at by scientists within a single discipline let alone outside that discipline.

In CAMS's brief history, investigators have generated more than two dozen scientific papers and technical reports. They have made some startling discoveries by looking in places no one had looked before. They have been exploring—through modelling and theory—the pathways materials take in the ocean. Jenkins characterizes their work in this area as one of "little conceptual breakthroughs." They have reviewed whole sets of data and literature on fisheries ecology and ocean circulation to uncover inherent biases in past analyses because of a lack of certain types of data. They have turned more than one theory on its head. A good example is their theoretical work in geodynamics—or the movement of the Earth's crust.

Liquid Earth

The physical surface of the planet changes constantly because of the complex and not entirely understood movement of plates on which all the continents lie. Of fundamental importance in understanding the Earth's moving crust is the mid-ocean ridge where new earth, in fiery belches and gigantean stretching, is being born. The mid-ocean ridge, which is the largest mountain range on Earth, winds its way around the globe in a trail of earthquake and volcanic activity. For the most part, the ridge system lies on the ocean floor, rising above water only in Iceland, the Azores, and East Africa. The major tectonic plates meet all along this globe-girding mountain range. As the plates pull apart—at about the rate a thumb nail grows—molten magma rises to the surface from deep within the Earth. The sizzling crimson magma oozes from cracks and volcanoes in the seafloor, much like toothpaste coming from a tube. Its outer skin cools quickly and hardens into glassy, black, lumpy, tubular, and pillow-like clumps that form new seafloor.

Less understood is why the chemistry of magma varies from place to place; how it migrates up through solid rock and gets channeled to the surface.

Three WHOI scientists—Henry J. B. Dick, a marine geologist; Hans Schouten, a geophysicist; and John (Jack) Whitehead, a physical oceanographer—were among those who attended one of the first CAMS geodynamics lectures.

Schouten's specialty is sea-floor spreading and magnetic anomalies. Dick is knowledgable about the composition of the Earth's mantle. Both men were independently studying different processes at the mid-ocean ridge. Schouten was looking at fracture zones—deep chasms that apparently result from periodic faults along the spreading ridge system. Some of these massive cracks stretch across the ocean floor for thousands of kilometers. He believed that these fractures developed in a regularly-spaced pattern along the ridge system. But if they did not develop randomly, what underlying mechanism was responsible for the even spacing? Another mystery intrigued Dick. He knew there was magma beneath the fracture zones, but he could find virtually no trace of it in the rocks he dredged from these deep valleys. His chemical analyses showed repeatedly that magma had formed in these rocks. Where did it go?

The mid-ocean ridge was not foremost on Whitehead's mind. He was using the principles of fluid dynamics in an effort to understand the formation of salt domes in Texas and Louisiana. "It never occurred to me," Whitehead says, "to apply those principles to spreading centers at the mid-ocean ridge."

The Interdisciplinary Connection

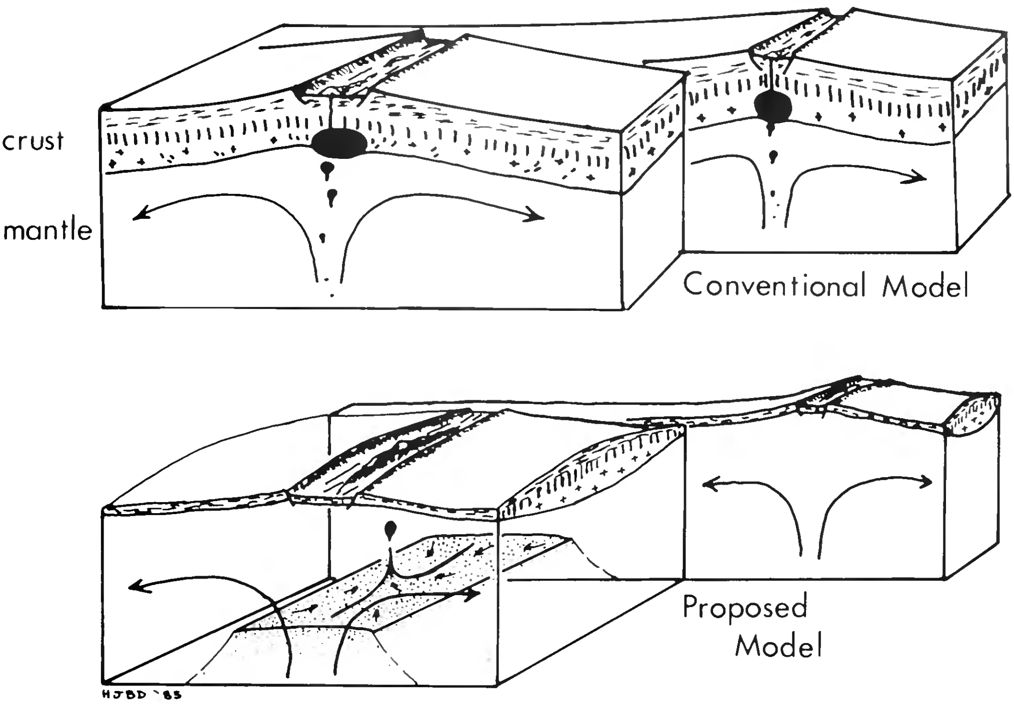
After one lecture, Dick chatted with Whitehead about his work. "Jack happened to mention," Dick recalls, "that fluids travel well laterally. And something clicked." Schouten was soon brought in on the discussion. "Somewhere in mid-sentence," Schouten recalls, "Jack started jumping up and down and pointed to this little piece of paper that had my model on it."

What had not occurred to Whitehead—or apparently anyone else—now struck him as obvious. The principle of fluid dynamics that he was applying to salt domes might explain the movement of magma beneath the Earth's crust. According to this principle, a layer of heavy fluid over lighter fluid causes a gravitational instability or, technically, a Rayleigh-Taylor instability. This phenomenon can be demonstrated with an old fashioned fountain pen and a glass of water. When a line of ink is forced gently onto the water, it does not drop in a single blob; it sinks slowly in a pattern of fairly evenly spaced fingers. The same principle applies to the inverse—rising ink.

Whitehead used corn syrup rather than ink to simulate the upward flow of magma beneath the spreading centers along the mid-ocean ridge. Because the viscous magma is lighter than the mantle rock from which it forms, a Rayleigh-Taylor instability develops, according to this model. The instability forces the magma out of the mantle, but not continuously straight up, as current scientific thought would have it. At some point in its ascent, the magma moves laterally—that is, up and to the sides into evenly spaced pockets from which the magma is channeled to the surface along the mid-ocean ridge.

This idea would explain why Dick could find virtually no evidence of magma in the rocks he dredged from the floor of the fracture zones: the magma beneath the fracture zones was migrating to the nearest pocket. In addition, the model implies that the laterally-moving magma caused the evenly-spaced segmentation pattern of the fracture zones.

The missing mechanism that Dick and Schouten could not find had come from a highly specialized physicist, a fluid dynamicist, who had to



In the conventional model, magma rises at random along the length of the mid-ocean ridge to form new crust. The CAMS' proposed model shows magma moving laterally into pockets, where it collects and then rises to the surface.

learn something about the language of earth science before he could help them.

"I didn't know anything about this mushy stuff," Whitehead says, referring to the magma or melt. "I didn't even know what to call it. You just can't underestimate the language problems. They are enormous. Every discipline has its own language and they are different worlds."

Researchers at Johns Hopkins University had applied the same principle of fluid dynamics to the formation of island-arc volcanoes. The CAMS investigators were the first to apply it to the mid-ocean ridge. They published their findings in the British journal *Nature* in 1984. This year, in a second research paper on the subject, Schouten, Whitehead and Kim Klitgord of the U.S. Geological Survey theorized that the spacing of ridge spreading centers is a function of the spreading rate. Their approach, one reviewer of this paper said, was "fresh and exciting." He continued in his letter to the editor, "It is much too early to tell if they are correct in their mechanical model, but the subject is so exceedingly fresh and at the cutting edge of earth science that it must be published." Another joint paper and another model, built on the first, are in preparation.

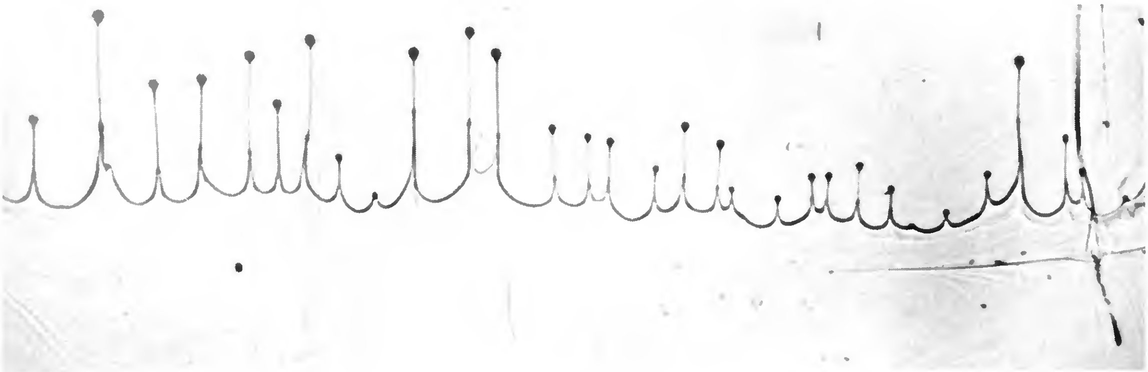
Too Wiley to Catch

CAMS brought together another unusual mix of people and data to explore the factors that regulate the year-to-year variations in the abundance of fish. With modern nets and acoustic detection equipment, we have seriously depleted many major fish stocks, including tuna, swordfish, salmon and sturgeon in the North Atlantic, and sardines in the North Pacific. But over-fishing does not tell the whole story. For instance, in the North Sea, populations of ground fish, such as haddock, increased markedly during the 1970s; at about the same time, herring and mackerel disappeared. Now, North Sea herring have begun to reappear—as unexpectedly and mysteriously as they disappeared.

In the usual CAMS style of high-level interdisciplinary interaction, biologists, physicists and fisheries managers reviewed the scientific literature on the variations of fish populations. In the course of their discussion and synthesis, it became increasingly clear that past research had focused almost exclusively on larval fish; there was scant data on juvenile fish. This was not too surprising to the scientists who had experienced the frustration of trying to catch these young fish. Despite the technological advances that have enabled us to deplete certain adult fish stocks, juvenile fish have proven too wiley to catch.

But the juvenile stage of development may play a role equally as important as or even more important than the larval stage. The juvenile stage lasts longer than the larval stage; thus, juveniles are vulnerable for a longer period to stressful biological factors such as food availability and predation by larger marine animals.

It also became apparent to the CAMS investigators that physical processes that were too often overlooked in past studies may significantly



A line of water and glycerine is infused in a bath of pure glycerine. Because the water-glycerine mixture is less dense than the pure glycerine bath around it, a gravitational instability results, causing a pattern of fairly evenly spaced protrusions.

affect the survival of both juvenile and larval fish. For instance, the Gulf Stream spawns warm-core rings, massive spiralling eddies that look and act like underwater tornadoes. These rings—some half the size of New England—may draw enormous amounts of water off the continental shelf, pulling larval fish that are helplessly adrift in the water away from their nutrient-rich spawning grounds. A severe atmospheric storm may have the same effect.

In cooperation with John Steele, the Director of WHOI, Patrice Klein, a physical oceanographer from the Station Zoologique in Villefrance-Sur-Mer, France, began data analysis and modelling in 1982. Klein's model built on his earlier work in Europe and on theories developed by Cabell Davis, a biologist at WHOI. The new models included not just the widely accepted biological factors, but also physical processes. They examined, for instance, not just the growth of plankton (the food of young fish), but also its transport by water currents. Steele and Eric Henderson of the Marine Laboratory in Aberdeen, Scotland, developed other models of long-term fluctuations in fish stocks.

Davis is expanding the Davis-Klein model with data on the Gulf Stream and atmospheric storms. Other CAMS participants are about to begin another vital, fundamental research project: learning how to catch juvenile fish. Before anyone can design the equipment to catch these young fish, scientists must know more about them. That calls for rearing larval fish in captivity and studying their behavior once they grow into juveniles.

There is much work to be done. The unanswered questions posed by new, unexpected scenarios and insight grow more tantalizing. The "CAMS connection" has been a dizzying intellectual high, Schouten says. "We have learned to communicate. I am learning more and more from the CAMS seminars. It gives one the opportunity for the exploration of ideas in someone else's mind. We are like a reservoir of seemingly strange mixes of chemicals. And we come to CAMS, the catalyst, to make some crazy concoctions that can make you high for years. It's very, very powerful stuff."

Victoria A. Kaharl is a Science Writer in the Education Department at the Woods Hole Oceanographic Institution.

References

Brewer, P. G., W. Broecker, W. Jenkins, P. Rhines, C. Rooth, J. Swift, T. Takahashi, and R. Williams. 1983. A climatic freshening of the deep Atlantic north of 50°N over the past 20 years. *Science* 222: 1237–1239.

Holland, W., T. Keffer, and P. Rhines. 1984. Dynamics of the oceanic general circulation: the potential vorticity field. *Nature* 308: 698–705.

Schouten, H., K. Klitgord, and J. Whitehead. 1985 (in Press). Segmentation of mid-ocean ridges. *Nature*.

Steele, J., and E. Henderson. 1984. Modelling long-term fluctuations in fish stocks. *Science* 224: 985–987.

Alcyone:
Le Navire Merveilleux

by Elizabeth Miller Collie

L'on a fait faire un navire
pour aller dans le levant
il est parti faire campagne
dans les mers de l'Orient.

Ah mon coeur n'a pas d'amant
*je passe mon temps gaillardement.**

Woods Hole was graced earlier this summer by a brief visit from the spanking new Cousteau Society ship, *Alcyone*. She is on her maiden voyage, which will reach around the world during the next five years. *Alcyone* is small for an oceangoing vessel—just over 30 meters in length. White and clean in appearance, *Alcyone* lies low in the water, and she is computerized in every aspect, sporting what her owners call "ultra-modern" equipment. However, it is her propulsion system that makes *Alcyone* special. She is Cousteau's hopeful prototype: a vessel powered by that timeless and powerful substance, wind.

Two tall towers, approximately trisecting the length of the vessel, are the interface between wind and ship's motion. The design is disarmingly simple. Each tower—called a Turbosail™ by the Cousteau-Pechiney association that produces them—operates like a vertical airplane wing, taking advantage of natural airflows (winds) to create lift, which draws the boat forward. Thrust from two diesel engines augments the Turbosails when the wind is low. *Alcyone* is able to save 20 to 60 percent of the fuel she would require with diesels alone.

Why should ships look to the wind for power? Supplies of fossil fuels are at times precarious and ultimately limited. Though no one is suggesting that oil supplies will disappear in the very near future, events in the very near past have demonstrated the volatility of the price of petroleum. Another consideration is the planet's health: burning fossil fuels contributes to pollution and to the increasing concentration of carbon dioxide in the atmosphere.

Wind is free and clean. Sails, the traditional technology for taking advantage of wind, underwent thousands of years of design improvements, but by the close of World War II working sail had been virtually abandoned by commercial shippers in the West. At that time, diesel power was going through a period of rapid improvement. Fuel for diesels was cheaper than labor to handle sails. Industry must attune itself to the market's pleasure, and market forces encouraged change to a technology that brought about speedier, more predictable delivery, greater safety at sea for the crew and ship, less hard physical labor for the crew, smaller crews, and other advantages in the handling of the ship and cargo.

Companies want to move their goods as speedily and economically as possible, and shipping is by far the most economical method of transporting bulk items like grains and ores across the oceans. However, as the price of fossil fuels rises, or fuel declines in availability, wind propulsion becomes more attractive to commercial interests. Several ship designers are investigating the practical use of wind power assistance for modern cargo carriers, and it is for this purpose that the Cousteau Society built *Alcyone*. She is a test platform. "The idea is to build commercial ships that can compete," Cousteau said to spectators on the Woods Hole dock. "We are not building a sailboat." Although *Alcyone* herself is

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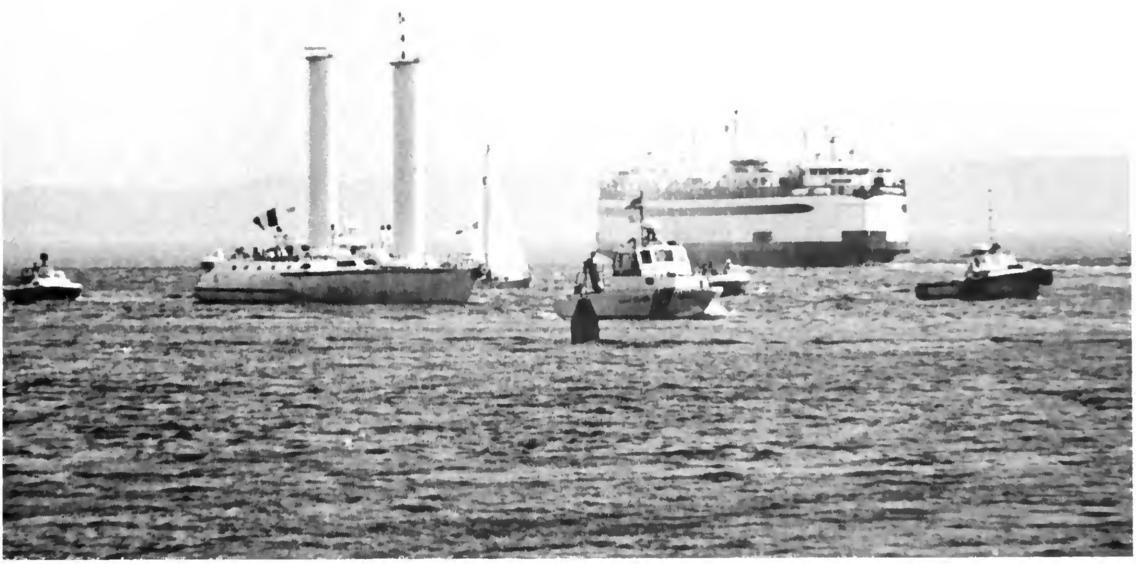
* "The Marvellous Ship," sea chantey (verse and refrain) sung when turning the capstan, a device for hoisting a weight by winding cable around a drum.

A ship has been built
to go into the east
it has gone to cruise
in the sea of the Orient

Ah, my heart has no lover
I pass my time jollily.



On a hazy Saturday in July, Alcyone *is escorted by the U.S. Coast Guard and several smaller boats through Vineyard Sound to Woods Hole, while the ferry* Islander *passes on her way to Martha's Vineyard. (Photo by Natalie Pasco)*

small, the principle behind her design is universal. The Cousteau Society says the Turbosail system will be readily adaptable to use on big commercial ships—an idea the society hopes commercial interests will buy.

Abuilding

The decision to build *Alcyone* was reached in February 1984. From that point, the process of design (by naval architects André Mauric and Jean-Charles Nahon), and construction (supervised by Bertrand Charrier) proceeded apace; studies began in early spring of 1984; the first aluminum plate (for the hull) was brought to the shipyard (Ateliers et Chantiers de La Rochelle-Pallice) in June, 1984. By March, 1985, the hull was in the water and being fitted with electronic equipment. The Turbosail towers, built in Lyon, were ready for mounting in early April. In May, *Alcyone* had her first sea trials.

Alcyone had a predecessor. Cousteau's first wind ship, *Moulin à Vent* (windmill), was a 20-meter-long catamaran fitted with a single Turbosail tower. She was launched in the spring of 1983, after several years of research into the Turbosail design. *Moulin à Vent* successfully navigated the waters around Marseille, but her Turbosail tower's attachment to the deck was too weak for ocean storms. The Turbosail tower was lost at sea in November, 1983, in a storm off Bermuda. The hull rests in Norfolk, Virginia (where the Cousteau Society has an office); according to Jacques Constans, Vice President for Science and International Affairs for the Cousteau Society, *Moulin à Vent* may be fitted with a new Turbosail tower, so that she can ply the Chesapeake.

Cousteau's second wind ship originally was named *Moulin à Vent II*, but Cousteau rechristened her *Alcyone* in keeping with the theme begun with *Calypso* (both names are from Greek mythology). The entire ship—its hull and Turbosail towers—is constructed of light and relatively non-corrosive aluminum alloys. Because aluminum weighs far less than steel, it is very attractive as a material for vessels such as airplanes and boats: lighter weight means greater cargo-carrying capability for the same amount of propulsion.

Alcyone resembles a yacht more than a cargo ship, because of her low build and small size. The unusual hull is a blending of three common shapes: the front is a monohull, the middle is flat, and the stern is double, like a catamaran. A catamaran-like stern permits *Alcyone* a reduced surface area (between pontoons the hull is above the waterline) so that in light airs she may gain speed. The broad, double stern makes for better stability.

The propulsion system comprises the two Turbosail towers and two diesel engines. The diesel component comprises two 156-horsepower diesel engines, each with a driveshaft and propeller. The engines, with a 20,000-liter fuel reservoir, supply the extra power needed in calms or light winds, and allow *Alcyone* to maneuver with ease when entering ports, docking, and in other potentially sticky situations such as staying off a lee shore.

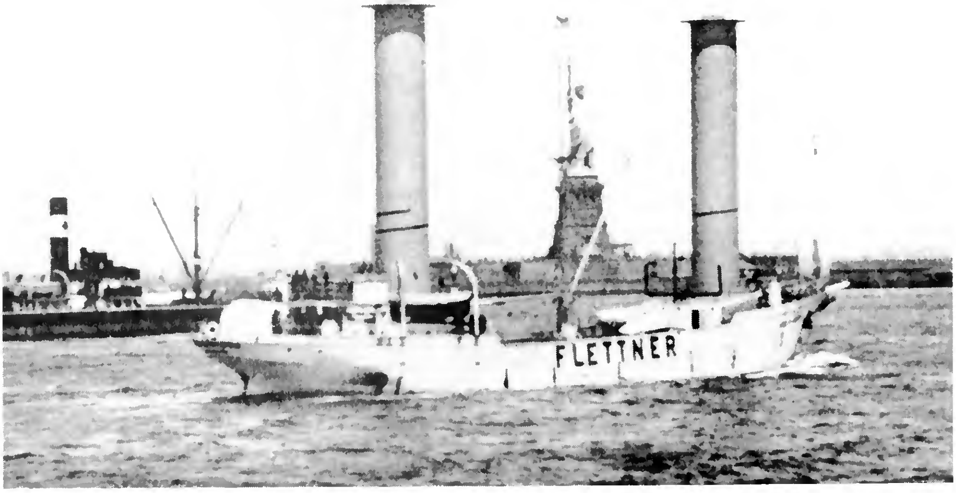
Turbovoile

If the Cousteau-Pechiney system is a propulsion model for the future, our harbors will not be filling with masts and rigging and thousands of sailors once more. The new vessel, though it enjoys the wind's generosity, requires no canvas, spars, sheets, and a minimum crew. Turbosail towers take the place of yards of fabric, miles of rigging, and endless fussing to adjust the rig. "Turbosail"—*Turbovoile* in

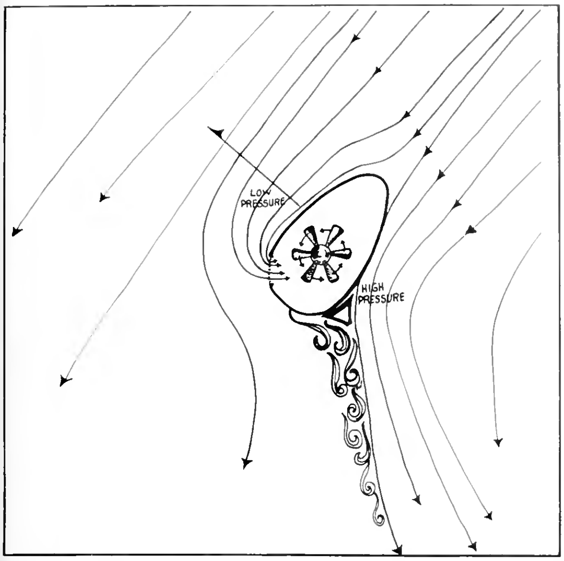
French—is simply a trade name coined by Système Cousteau-Pechiney* for what is their version of an aspirated thick airfoil. Aspirated and turbo both refer to the fan situated in the top of each tower. Onboard *Alcyone*, each Turbosail tower has a hydraulic generator of 25 horsepower that provides electricity to operate the fan and to position the tower. The bases of the Turbosail towers are incorporated into the shell of the vessel, a strengthening measure that should preclude their blowing overboard, as happened to *Moulin à Vent*.

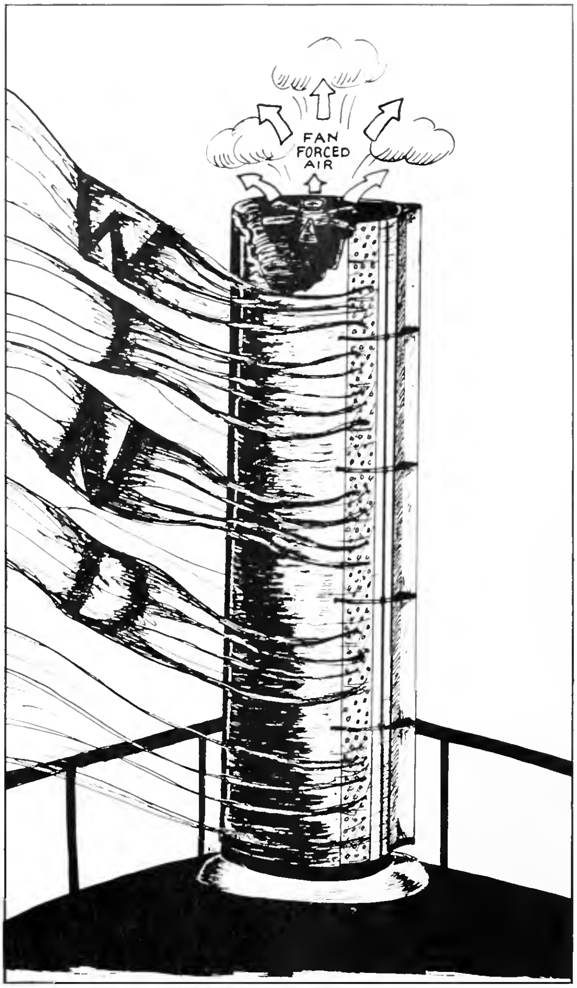
The idea for the Turbosail tower evolved from an earlier design, the Flettner rotor. In the 1920s, Anton Flettner, a German engineer, created a system for propelling ships that took advantage of a physical phenomenon known as the Magnus effect. Consider what happens if a cylinder is rotated (clockwise as you look down on it) around the center of its shaft. The thin layer of air immediately surrounding the cylinder is dragged by friction in the direction of rotation. Now consider what occurs when a flow of air (a breeze) bears across the cylinder: the breeze must pass to either side of the cylinder, and as it does, that portion passing on the three o'clock side of the cylinder is speeded by the force of the moving skin of air on the cylinder, while that portion of the breeze passing on the nine o'clock side of the cylinder is slowed by its meeting with the film of air coming from the opposite direction. Thus, the cylinder has a low-pressure area on its three o'clock side, where the breeze is speeded up, and a high-pressure area over by nine o'clock, where the airflow is slowed. Naturally, the cylinder itself is drawn forward into the low pressure area, because something must operate to correct the imbalance of pressures. As long as the cylinder continues rotating and the breeze keeps blowing, the cylinder will tend to move in the direction of low pressure. This is the

* Pechiney is an international company, headquartered in Paris, that is a major producer and processor of aluminum, among other things.



Above: *The crew prepares to dock. Two diesel engines facilitate this sort of maneuvering. (Photo by Shelley Lauzon)* At left: *The Flettner rotor ship in New York after crossing the Atlantic. (Photo courtesy* Yachting, *CBS Magazines, copyright June 1926)*





Above: *Turbosail action depicted from the top. The wind (represented by arrows originating top right) must pass to either side of the cylinder. On the lee side, the fan draws a thin skin of air in through the perforations, after which the air is exhausted out the top (see side view,* Right*). On the other side, the triangular flap further separates the two airstreams and narrows the area of turbulence. Lift is created in the direction of low pressure. The effect is exaggerated in these drawings.*

Magnus effect, named after the 19th-century German chemist who described it.

Flettner applied this concept by converting the topsail schooner *Buckau* into a rotor ship. He removed the masts and installed two rotors, each about 50 feet high and nine feet in diameter, and rotated by electric motors at speeds of up to 140 revolutions per minute. The ship, rechristened *Baden-Baden*, made several successful Atlantic crossings. Practice proved that the rotor ship could sail closer to the wind than she could when rigged as a topsail schooner; tacking, changing course, and other maneuvers required only that the rotor speed be varied—a much simpler operation than trimming and changing sails had been.

The Flettner rotor design was not widely adopted, despite its advantages over traditional sail technology, chiefly because of timing: in the early 1930s, diesel engines were coming into their own, and fossil fuel was cheap. In earlier times, concern for the crew's safety was not paramount, even though sailing was a hazardous profession; at this juncture, it's easy to see why modern designers do not want to install giant spinning tubes on deck: they're unwieldy, cumbersome things that rotate at high speeds, a danger to people and equipment nearby.

The Turbosail tower gets around the difficulties posed by an ungainly spinning tower by creating the low- and high-pressure zones, responsible for the ship's forward motion, in a different way. Rather than spinning the cylinder to create the necessary differential pressure zones, a thin skin of air is drawn into one side (the cylinder is hollow) and exhausted out the top by a fan. This speeds the air's passage on that side of the tube, and a low-pressure zone is obtained. A cross-section of one of *Alcyone*'s Turbosail towers reveals that instead of being round, it is shaped like an egg, with the pointy end toward the bow of the boat. Down both sides of the fat end of the tower the aluminum is perforated to allow air intake. A fan placed at the top of the cylinder sucks air in through the perforations and moves it out the top. To complete the streamlining, a triangular flap is positioned over the perforations on the side of the Turbosail tower away from the direction of travel. To increase efficiency, the entire unit can be turned to position it in the most advantageous way relative to wind and course headings. A simple gear of the type used on public-works cranes turns the Turbosail tower.

The size and purpose of a ship would determine the size Turbosail system it would need to propel it adequately. *Alcyone*, at 30 meters long and 9 meters beam, displaces about 80 metric tons when half-loaded; her two towers are each 10 meters high with 21 square meters surface area. The Cousteau-Pechiney engineers suggest that for a seagoing merchant vessel weighing 30,000 metric tons empty,

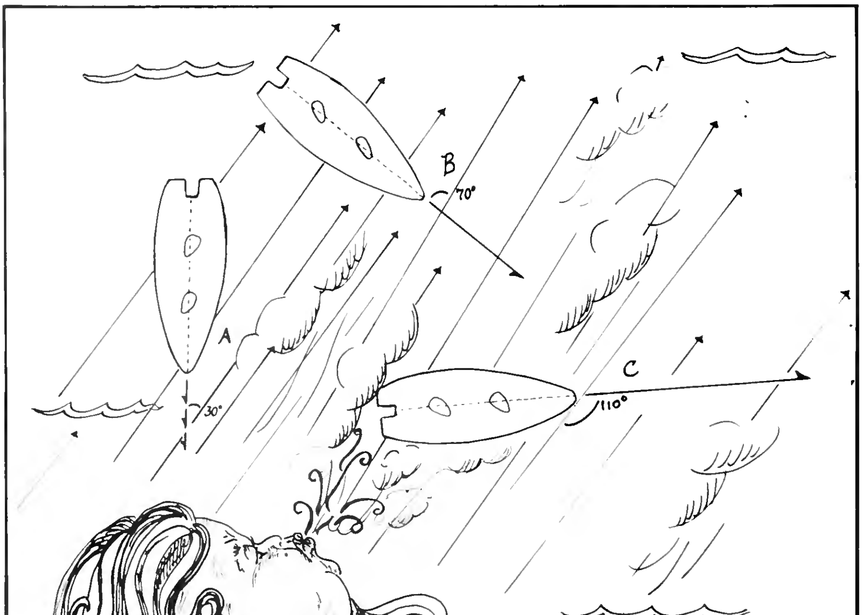
Inside the wheelhouse: Richard Murphy (on left), vice president of science and education for the Cousteau Society, gives Robert Ballard of WHOI an education in the science of Alcyone's *electronics. (Photo by Shelley Lauzon)*

two turbosails with surface areas of about 200 square meters each would be necessary.

Alcyone's drive system performs best when the wind is coming across the ship at a relatively wide angle (between 70 and 120 degrees). A wind speed of 30 knots allows *Alcyone* to make 10 to 12 knots using just her Turbosail system. "A rule of thumb," says Constans, "is that the speed of the ship will be one-third the wind speed."

Onboard *Alcyone*

The new vessel requires as few as three to crew her, and has accommodations for up to twelve. One complaint against sailing ships of yore was the number of sailors needed to operate them—songs and stories about press gangs and lousy contracts are legion. In today's world, few men or women desire a career involving years away from home, low pay, hard physical labor, constant danger, and poor accommodations on the moody sea. However, the sailing ships of tomorrow could require no more crew than the motor ships of today, and hard physical labor—at least in the actual sailing—may be a thing of the past. When she arrived in Woods Hole, *Alcyone* had a crew of five (the normal crew for transoceanic trips): the captain, an electronic engineer, the chief engineer and his assistant (who's also the cook), and a computer specialist. Although the captain was specially chosen for his experience racing sailboats around the world, it's the computer technician who will be as essential in the future as the chief engineer. Every operation aboard *Alcyone* is computerized. Two computers (standard off-the-shelf models) operate on board the ship. One actually comprises a computer plus a robot; the robot instructs the drive system under the supervision of the computer. To accomplish the most effective balance between sail and motor power, and to gather data to document her condition and achievements, the robot continually monitors the world around *Alcyone*. There are nearly 50 sensors on board, keeping track of wind direction and force, the angles of the Turbosail towers, the



Preliminary results suggest the Turbosail system can work as closely as 30 degrees to the wind (A), but Alcyone *performs best when she has an angle of between 70 degrees (B) and 110 degrees (C) with the wind. A, B, and C all depict* Alcyone *on a starboard tack; a port tack would work equally well.*

thrust of the propellors, and many other parameters. Strain gauges monitor the vessel's construction, testing the strengths and weaknesses in the structure so that improvements can be made.

The second computer is used for program development and for analyzing data acquired through the first system. The data will be used to convince ship designers and owners around the world that sail-assist is a practical, available technology.

One disadvantage of living aboard such an up-to-date machine is that the interior must be kept air-conditioned for the computers' sake. Hatches must be kept closed. Apparently the crew dislikes this shut-in life—they lose touch with the sea. One advantage of wind-propulsion is its quietness, and *Alcyone* is a quiet ship, according to her crew. However, though she does not heel as would a traditional sailing vessel, neither do the Turbosails cushion her roll (old-fashioned sails absorb some of the roll, making a more comfortable ride). *Alcyone*'s roll is a rather rapid motion that takes some getting used to.

Performance

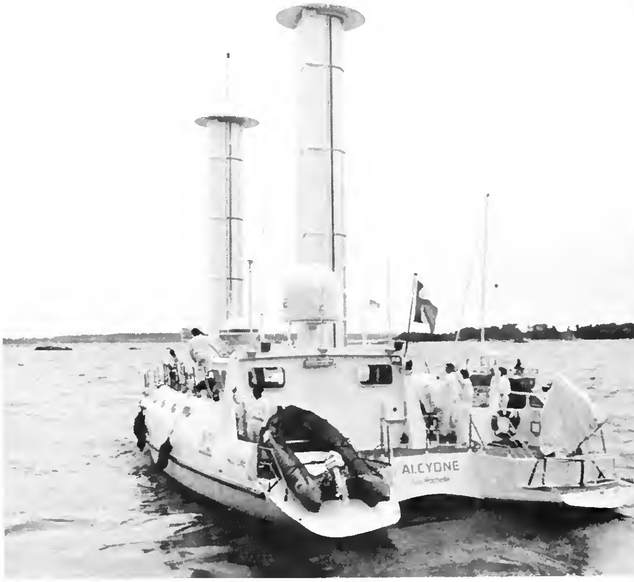
So far, so good, report Cousteau and Constans. On *Alcyone*'s recent Atlantic crossing she ran into some calm waters and had to motor more than is desirable. "The ocean was absolutely flat for 10 days," said Constans, "very unusual." However, the Turbosails were in fine fettle on the leg from La Rochelle to the Azores and again from Bermuda to New York. Results of tests on the drive system are "very encouraging"—with the wind at the optimal angle (between 70 and 110 degrees), *Alcyone* accomplished greater than 50 percent energy savings over what would have been required without Turbosails.

Alcyone can continue to make headway at about 30 degrees to the wind—perhaps a little closer than could a conventional sailing ship. The Turbosails appear to lend a high degree of maneuverability. We were able to observe this phenomenon at the Woods Hole dock, as Cousteau twiddled the Turbosail controls, turning the cylinders and moving the flap, *Alcyone* responded by moving in and out from the dock, as far as her tethers would let her. Constans thinks that an aerodynamic positioning system will be possible eventually, "but we still have a lot to learn."

Future Trials

In the next two years, the plans for *Alcyone* include a voyage around the world during which she will stop in all major maritime countries. After spending some time in Norfolk, she will wend her way through the Caribbean and down the east coast of South America to Patagonia; from there *Alcyone* will round Cape Horn and voyage up the west coast of the Americas, reaching Vancouver by the summer of 1986. The Cousteau people hope to interest ship designers and builders, but primarily ship buyers, in the Turbosail system. Thus, *Alcyone* will spend at least several months in the Far East—Japan, South Korea, Taiwan, China—where many commercial ships are built today.

During this long voyage, the Turbosail drive system will undergo extensive testing to prove its capabilities and to determine where improvements are needed. Cousteau is considering building a replacement for *Calypso*, which would have a drive system like that of *Alcyone*. As well, *Alcyone* will contribute to the conventional Cousteau mission, participating in underwater filming projects and some limited science (exactly what is not yet defined).

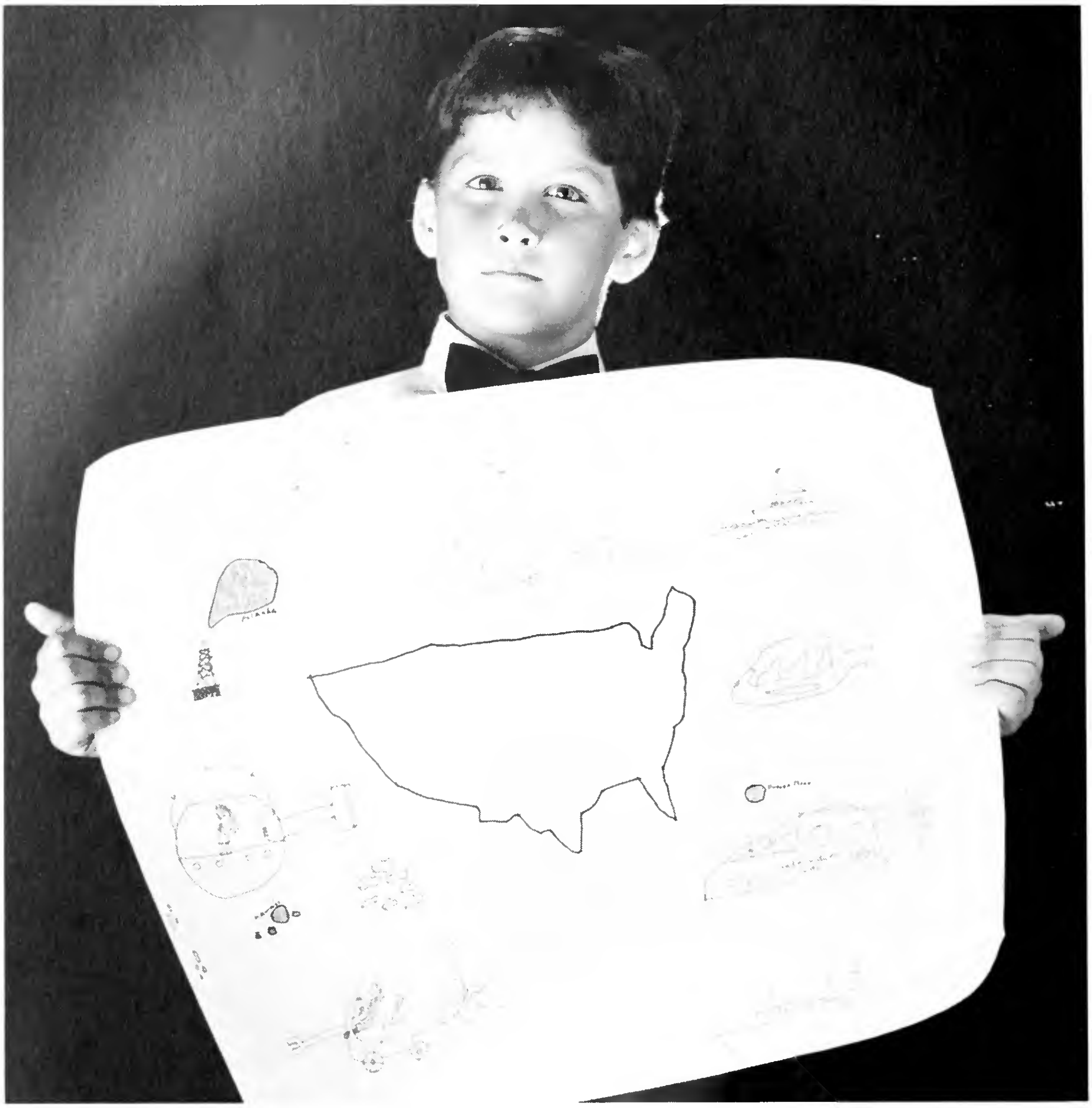


Alcyone, with her catamaran-style stern revealed, departs Woods Hole; her crew waves goodbye. (Photo by Anne Rabushka)

Many oldtimers and coastal dwellers with romantic turns of mind bewail the demise of working sail. Today, we can only imagine, with the help of old photographs and occasional visits from peaceful, antique armadas like the Tall Ships convocation in 1976, what was once taken for granted: the sight of many ships in full sail. Cousteau's idea, if popularly adopted, will not restore this grand, romantic vision. Sailors, however, will welcome the new technology, because it makes their lives a little easier.

The wind has not slackened for lack of commercial exploitation in our part of the world—skittering boardsailors and unprecedented numbers of pleasure craft attest to its power and availability. If the oil supply should expire, the wind will yet exist, for literally as long as the Earth turns and the sun shines, wind is guaranteed. The grace of the wind is lent any vessel that borrows its power; may fair winds accompany graceful *Alcyone*, the marvellous ship.

Elizabeth Miller Collie is Assistant Editor at Oceanus.



profile Charles Francis Adams

Honorary Oceanographer

by Paul R. Ryan

Charles Francis Adams, direct descendant of John Adams, the second President of the United States, and John Quincy Adams, the sixth President, has made a significant contribution to oceanography, specifically to the growth and health of the Woods Hole Oceanographic Institution (WHOI).

Many who make significant contributions to marine science are not, strictly speaking, researchers. They do not, for example, hold advanced degrees in scientific disciplines. Adams is such a man. His contribution to marine science has been in quietly lending his influence, advice, and business expertise to WHOI during its expansion years—a period that has seen the Institution become one of the most respected centers of marine research in the world. Adams retired as Chairman of the Board of Trustees of the private, non-profit corporation that runs the Oceanographic in June of this year after 12 years' service in that position.

Born Charles Francis Adams, Jr., on May 2, 1910, in Boston, the son of Charles F. and Frances (Lovering) Adams, he attended St. Mark's, a private boarding school in Southboro, Massachusetts, where he played on the football team, the hockey team, and rowed in a four-oared crew. St. Mark's archrival is Groton. "We used to be to Groton as Harvard is to Yale," Adams commented.

By his own admission, Adams was not the best of students. "I didn't stand where my father and mother would have liked me to. I'm sure that caused them a lot of grief, but in the end I did stand equal to the fellow who led our class all the way through school when it came to college exams, so there must have been latent abilities, and that redeemed me with my father."

Was there pressure on the young Adams to grow up in a certain way because of his lineage back to two Presidents of the United States, and an Ambassador to Great Britain? "No. A lot of members of the family wrecked themselves in the past trying to emulate some ancestor. I decided I wasn't going to worry about that. I'd go ahead and do my own thing in my own way.

"I never had any pressure from my father along those lines. He offered very little gratuitous advice. He gave a great deal of good advice when I asked for it, but he did not tell me how to run my life, except in the minor aspects of giving a son hell if he wasn't doing what he ought to be doing. Of course, he did say 'you ought to behave yourself,' and 'remember that good manners never hurt you,' and a few of those other things that any boy would get from a reasonable parent."

The Adams family lived in a curious way. "We lived in Boston in the wintertime. In the spring and fall, we had a place in Concord. Summers we spent at an establishment called 'The Glades,' which is down on the South Shore near North Scituate. It was there that we first dabbled about in small boats." The boats would get larger over the years; the sailing competition keener.

The investment banking business had become singularly unpopular, so I picked it as an area of minimum competition to look for a job!

In fact, the young Adams would win one race in an America's Cup "trial horse" in 1929. According to *Yachting* magazine, "Charles Francis Adams, Jr., a Harvard sophomore and son of the Secretary of the Navy, sailed the *Vanitie* in the run from Boothbay to Portland, made in very light airs. The youngster made a fine start but lost the lead to *Resolute* by not following her inside of Seguin. At one time the old cup boat was a quarter of a mile ahead. Then the *Vanitie* picked up a breeze offshore and slipped out ahead again, and as the *Resolute* slumped into the doldrums, the Lambert boat won the race by over 15 minutes, the widest margin between yachts so far this season."

The Navy Connection

Adams's long association with the U.S. Navy had begun the year before (1928) when he had participated in an ocean race from New York, N.Y., to Santander, Spain. The navigator aboard the yacht was a young naval officer by the name of Felix Johnson, "who I came to like tremendously. He was a very attractive character; we talked a lot about the Navy on the passage over. When we got to Santander, there was an American cruiser in the harbor and some foreign warships. The King of Spain gave us a reception and dinner. Johnson got me so interested in the Navy that when I went to Harvard in the fall of 1928, I signed up in the Naval Reserve Officers Training Course.

"When I graduated from Harvard in 1932, I was commissioned an Ensign in the Naval Reserve. I promptly got aboard a cruiser and went from Boston to the West Coast. Then, I transferred to a battleship for a couple of weeks to get a little more feel for the Navy at first hand. After that, I joined what they called the Organized Reserve.

"I was ordered to active duty in the Navy in November, 1940. So, by the time of Pearl Harbor, I had been in the Navy more than a year on a destroyer, the last four months on convoy duty. Then I went to the Naval War College for six months. I was kept there as an aide to the President of the College and on the staff for a few months more. Then I went to the Submarine Chaser Training Center and became the skipper of a couple of destroyer escorts. I was Acting Commander of a division of them for awhile. Then, I was assigned to the staff of the Commander in Chief of the Atlantic Fleet.

"We never actually pinged on an enemy submarine. The only thing we ever pinged on turned out to be false targets. However, in the Pacific, there were a lot of kamikazes. We fired a few rounds at them, so we were in an anti-aircraft role as well as an anti-submarine role. My last action was at Iwo Jima. The fall of 1945 was spent in the Navy Department in Washington planning the post-war Naval Reserve. I left the Navy in April, 1946, with the rank of Commander."

On June 16, 1934, two years after graduating from Harvard with an A.B. degree in

Fine Arts, Adams married Margaret Stockton of Manchester, Massachusetts. Three children followed: Abigail (Mrs. James C. Manny), Alison (Mrs. Paul Hagen), and Timothy, now in the automobile business in Boulder, Colorado. Adams's first wife died in 1972. In 1973, he married the former Mrs. Beatrice D. Penati. He has nine grandchildren by his two daughters.

After his undergraduate work at Harvard, Adams attended the Harvard Business School, following which he got a job with Jackson Curtis, which later became Paine, Webber, Jackson, and Curtis. He became a partner in that well-known securities firm in 1937. He would remark in the 25th anniversary report (1957) of the Harvard Class of 1932:

"On leaving the business school, it seemed to me that the investment banking business had become singularly unpopular, so I picked it as an area of minimum competition to look for a job! An association with several able and imaginative partners, as well as with some interesting industrial companies that we financed, made this a reasonably rewarding experience, both financially and otherwise....

"After the war, there seemed to be something lacking in the investment business, and when an opportunity came along to try to work out some management problems at Raytheon Manufacturing Company, I grabbed the chance. The electronics industry presents a fascinating and ever-changing challenge and there has never been a dull moment since! Important contributions to the military and building jobs here in Massachusetts, where some of the traditional industries were slipping badly, has made the effort appear well worthwhile. It has been interesting to try to see how a liberal arts education at Harvard can fit in usefully in an organization so largely composed at its upper levels of scientists and engineers."

Charles Francis Adams at the helm of Vanitie, *1929.*

27 Years at Raytheon

There was more to it than that, of course. Adams is a master of understatement. Prior to World War II, he was both a Director of Raytheon and of the Submarine Signal Company, which merged after the war, the latter company eventually becoming a division of the former.

During his 27 years of direct participation in the company's management, which culminated with his retirement in 1975, Raytheon's sales grew fortyfold—from $54 million to almost $3 billion. From 1947 to 1975, Raytheon, which eventually was to employ more than 55,000 people, grew from an electronics firm to one that is a prime contractor for missiles and other defense and non-defense items to the government; a significant force in the household appliance field; a major contributor in the energy development field; a publisher of textbooks; and a manufacturer of heavy equipment for roadbuilding.

Adams would remark in the 50th anniversary report (1982) of the Harvard Class of 1932:

"I retired in 1975 as an active executive of Raytheon Company, but when asked by my successors to remain as a consultant, I happily accepted, and continue to give considerable time to the affairs of this interesting enterprise, which for 27 years was my total occupation.

"As a card-carrying member of the military-industrial complex, I am proud of the fact that we have made significant contributions to defense while, at the same time, I cannot but view with alarm the continuing escalation of military force around the world.

"Although the Soviet Union appears to grow as a force menacing the Western world, I would feel more comfortable in leaving the scene to our children and grandchildren were there some visible and significant progress in negotiations leading to a reduction of both nuclear and conventional arms. Although the balance of power has so far kept the peace between the major powers, this is scarcely a promising way of life for the generations to come."

Ethics in Business

Adams has always been a champion of ethical dealings in business, a notion that has its roots for him back in the 1920s when his father was involved in finding money to build the original elements of the complex of buildings that is today the Harvard Business School. Aiding his father in the fund raising effort was the late William Lawrence, Episcopalian Bishop of Massachusetts, who hoped that the teaching of ethics in business would be woven into the fabric of that institution. Adams summed up his thoughts on the role of "The Executive" at the Cambridge Forum on Great Vocations—Issues in the

Professions, on November 30, 1977:

"One of the most perplexing problems confronting industrial management today ... is the question of business ethics...

"A chief executive is hired by his board of directors, in the interest of the shareholders, to run the business at a profit. Let me hasten to add that there is nothing wrong with profit...

"While it is popular now, and often has been in the past, for politicians, the press, certain academics, and others to attack the idea of a profit as being something bad, let me remind you that without profit, our enterprise system can only falter and collapse...

"Without profits, past, present, and future, the capacity of Harvard and the Massachusetts Institute of Technology to pursue their objectives of teaching and research for the eventual benefit of mankind could wither and fail...

"That there are more than ample opportunities for abuse of the system, and for wrong-doing in its operation, I would not for a moment deny... Examples have been only too evident in recent years.

"Illegal political contributions, hidden slush funds, bribes paid to foreign officials, and a variety of other forms of corporate wrong-doing appear to have reached epidemic proportions. One trusts that this pattern of behavior, having peaked at a disgraceful level, will, like many an epidemic in the medical sense, now tend to recede.

"What the impact of an unpopular war, followed by the lowering of standards which led to Watergate, may have had in creating this messy situation, we may never understand, but we do know that these shady doings, if by only a few, have shed a pall of public distrust over all of us. It will take time and effort for the business community to create visible evidence of acts designed to restore public confidence..."

Adams today remains a strong advocate of ethics in business, although he feels the press has sometimes distorted instances where businesses may have legitimate reasons for charging the military or government agencies for expenses that appear on the surface to be ridiculous. Adams explained: "Without getting into a 'holier than thou' point of view, I can say that when I was at Raytheon's helm we did our best to avoid charging the wrong things to government contracts. But you never can be sure that there isn't some fellow down in the system somewhere who didn't pay attention to the rules. We have had cases where our internal auditing system has found such people and we have fired them and reiterated the rules of the game. We continue to try to avoid practices that we consider to be dubious."

Dr. Bigelow had decided he'd better get every bloody damn thing he could out of the Navy while his friend Charlie was Secretary of the Navy.

Remembrance of Bigelow

Adams still has great respect for his father. The senior Adams was at the helm of the *Atlantic* on the race to Santander in 1928. Indeed, the yachting exploits of his father were legion.

In 1920, he defended for the United States when the yacht *Resolute* defeated the *Shamrock*, owned by Sir Thomas Lipton, the famous British skipper, in one of the latter's several attempts to capture the America's Cup. The *Shamrock* in that contest won the first two races, while the *Resolute* evened the score by capturing the next two. In the final race, the *Resolute* trailed until near the finish, but in a brilliant spurt nosed out the British craft.

The elder Adams, Harvard's treasurer for 35 years, was appointed Secretary of the Navy in 1928 by President Herbert Hoover. And it was about this time that the younger Adams became aware of Woods Hole.

"I remember as a teenager listening to a conversation between my father and his old friend and neighbor, Dr. Henry B. Bigelow, in which Dr. Bigelow (first Director of WHOI and Alexander Agassiz Professor of Zoology at Harvard) expressed his conviction that an institution should be created for study of the oceans.

"Dr. Bigelow lived quite near my father and mother in Concord. Both men were interested in the sea. My father was a racing-type yachtsman, he didn't give a damn about cruising, but he did care about the sea as a result of this. Dr. Bigelow used to come up to see my father and I remember them chatting. Dr. Bigelow saying in effect, 'you know Charles, we really ought to found a proper institution to do research in oceanography. Somehow or another we ought to put that together.' Well, in the spring of 1929, my father went to Washington. Dr. Bigelow got in touch with him one day soon after and said 'I've gotten a Rockefeller grant—we've started on the oceanographic institution.' Dr. Bigelow had decided he'd better get every bloody damn thing he could out of the Navy while his friend Charlie was Secretary of the Navy.

"There ensued some wonderful correspondence (see *Oceanus*, Vol. 14, No. 2). 'Dear Charlie, we need this, that, and the other thing, love, Henry.' That kind of thing. And back, 'Dear Henry, I've instructed so-and-so in the Navy to look into the matter and see if they can be helpful to you.' Obviously, the Navy was interested in oceanography. There were good reasons for them to support Woods Hole, not just because these two characters happened to be chums. The Navy still supports Woods Hole, and depended enormously on it in World War II, all of which flowed out of this original correspondence.

"When my father came back from Washington in 1933, Dr. Bigelow asked him to become a trustee of the Oceanographic, which he did for a while. When he died (in 1954), I was asked to take his place. As a result, I used to go to meetings in Woods Hole. Dr. Bigelow provided horrible little box lunches for us, but we had very interesting meetings. He presided in his own peculiar way; had a quaint style all his own.

"Columbus O'D. Iselin was the Director through the war. Obviously you did what you had to do during the war, but what Columbus wanted to do was research. He did not want to be an administrator. He didn't want to direct the place. He made that clear to Dr. Bigelow. So they went through the process of finding a man to do it and they came up with Rear Admiral Edward H. Smith, U.S. Coast Guard, known to all his friends and contemporaries and others as Iceberg, because he had been assigned to chasing the Germans out of Newfoundland in the war.

"Iceberg, as I remember it, had a degree in Physics from Harvard, so he had credentials as a scientist and obviously experience as an administrator, being a senior Coast Guard officer. So he was duly appointed Director.

"Iceberg's view of how to deal with things was like the taut administration that you have in the Coast Guard. It just didn't fit with the scientific style. Although I liked Iceberg—he was an admirable man in every way—it was a mismatch. He didn't quite fit in at Woods Hole. So eventually all those concerned decided that Iceberg had to leave. The last thing we could afford to have was a revolt on the part of all the scientists, who were brilliant as scientists, but almost unmanageable as a group. I think the only group that could be more difficult to manage would be the faculty at Harvard, and that's only because there's more of them, not necessarily because they're more difficult.

"Columbus was then dragooned back into being Acting Director until we could find somebody else. At that point I got on the search committee for a new director, which was chaired by the late Detlev Bronk. After a long search we found Paul Fye. He had the extremely difficult job of creating an orderly administative effort at the Institution, while still keeping the scientists reasonably satisfied.

"Although he had a lot of trouble with certain people as time went by, Paul accomplished a lot of things during his long tenure as Director: he provided a suitable administration, that is suitable to the nature of the Institution and to the character of the scientific staff which worked and which kept the people from getting into each other's territory—an orderly arrangement. On top of that, he introduced—despite considerable opposition—the educational aspects of the Institution. Burr Steinbach was appointed dean and got that off to a good start. Again, despite the early opposition, virtually all agreed in the long run that Paul had been right.

The only group that could be more difficult to manage [than WHOI scientists] would be the faculty at Harvard, and that's only because there's more of them . . .

"If there be merit in the old saying that research and teaching go hand and hand, then what a waste if there were no mechanism by which the imagination, skills, and knowledge of the Institution's brilliant staff could be passed on to another generation of promising young men and women who seek to establish careers in ocean science.

"When Paul Fye's retirement came along, we formed another search committee of Trustees, backed by an internal advisory committee. From the latter group came the suggestion of John Steele as Director. As our deliberations continued, and we reviewed a considerable number of distinguished candidates, John's name emerged as our clear choice. If there has been any one event on my watch for which I can justly take pride, it has been bringing John to Woods Hole as Director. He has more than lived up to our brightest hopes."

In looking to the future, Adams stressed the importance of satellites to oceanography in the next decade as well as new unmanned submersibles of the type being developed at WHOI by Robert Ballard (see *Oceanus*, Vol. 25, No. 1). On the question of doing science that is related to national security, he stated: "I think it's proper that the scientific staff at Woods Hole stick with basic research. However, if the only money that is available, or if a significant part, gets tied to applied science, I would favor a certain degree of compromise.

"The Institution's future role, as I see it, is to maintain its quality, to enhance it if that indeed be possible, but never to settle for anything less than the best. To keep our share of the monies available for research in oceanography, we must be able to produce better evidence of work well done per dollar spent than any competitor. Be this by more creative and original papers, by more convincing solutions to complex scientific problems, or by more productive work per day at sea, we must keep our lead in such clear and evident fashion that there can be no question as to who is number one. Better to me to accept the circumstances that might some day arise in which it might be the course of wisdom to drop a certain activity, than to carry it on in a second-class manner.

"What then one might ask is the role of the Chairman of WHOI? To me, it has been to advise, to encourage, to be available to help in any way possible when called on by the Director, and at the same time, with the Executive Committee to reach decisions on important matters of policy and administration. Within all this there is one procedure which I have come to see as the clear essence of our role, and that is the approval of appointments to tenure and to senior rank. I was impressed from the start by the rigor of this procedure, and have never changed from my

Charles Adams with John Lehman, Secretary of the Navy, 1982.

commitment to the view that the essential quality of the Woods Hole Oceanographic Institution derives from the care and consistency with which the selection and the promotion of scientific staff has been carried out."

Community Leader

Charles Adams has always been deeply involved in community programs in Massachusetts. He, like his father before him, for example, has been a leader in development of the United Way. He also was a driving force behind the establishment of the museum in Boston for "Old Ironsides," launched as the U.S.S. Constitution during the administration of President John Adams, and has been President of the Freedom Trail, one of the largest tourist attractions in the state. These activities led *Boston* magazine in 1975 to propose Adams as a candidate for Mayor of Boston, commenting "there are certain mossbacks who believe there should always be an Adams in office."

The awards over the years have been numerous. In 1981, Adams was named the first recipient of the Fleet Admiral Chester W. Nimitz Award given by the Navy League of the United States for making exemplary contributions to the nation's maritime strength and its national security.

My interview came to a close. Adams, nattily attired in a gray suit on a sweltering summer day, rushed off to a business luncheon and left me in his office at Raytheon with some 12 books of clippings to look through to round out my profile. Nautical books were in abundance around the room, which was ample in size, but I suspected smaller than when he was Chairman of the company. On the window-sill there is a model of the *U.S.S. John Adams* SSBN 620, a ballistic nuclear missile submarine built by the Portsmouth Naval Yard. There also is a model of the Sparrow 3 missile built by Raytheon. But occupying a prominent place on a coffee table before a couch is a superbly-crafted model of the sailing ketch *Atlantis*, presented to Adams on his retirement as Chairman of the Board of Trustees of WHOI. *Atlantis* was WHOI's first research vessel. A cartoon on the wall caught my eye. It is of Adams in an old American admiral's costume, lifting his tri-cornered hat near the Bunker Hill Pavillion, the *U.S.S. Constitution* in the background. Escaping out of his mouth is a little blurb that says: "Tourists come back."

As I left the office, I was reminded that Adams had told me he would soon be off on a cruise to Maine, with his 83-year-old sister, Mrs. Henry Sturgis Morgan, on his 58-foot ketch, based in Padanaram, Massachusetts. "Her boat is laid up, and being without a boat at this time of year is sort of like a bird without wings," Adams had commented.

Adams has a special place in his heart for the great auk—that flightless, aristocratic bird that became extinct in the late 1840s.

The image of the bird made me recall that Adams has a special place in his heart for the great auk. He has named four of his sailboats over the years after the flightless, aristocratic bird that became extinct in the late 1840s after the last one was clubbed to death by people who wanted to stuff pillows with its feathers. The great auks once migrated by swimming from the Iceland/Greenland area to North Carolina, a distance of some 3,000 miles, including a passage through Woods Hole. "My father had a boat called *Auk* and it appealed to me because, if you dropped the 'great,' it was a short and neat name. Didn't have to pay the sign painter too much," Adams said, a twinkle in his 75-year-old eyes.

Acknowledgment

A few of Mr. Adams's remarks quoted in this Profile were delivered during a dinner in his honor at Clark Laboratory, WHOI, on June 13, 1985.

Expeditions

Below, the Hokule'a fully rigged for sea in early July, 1985, a few days before departing for Tahiti. (Photo by Mike Tongg)

Navigating Without Instruments:

The Voyages of *Hokule'a*

by Edward D. Stroup

Experienced navigators readily accept the possibility of deliberate, long-distance navigation by early Polynesians; it is landlubbers who have trouble believing that a person can find his way over thousands of miles of unmarked ocean without the help of modern instruments.

I began to realize this while analyzing the 1980 voyage of the sailing canoe *Hokule'a*,* which left Honolulu in mid-July of this year on a third voyage of rediscovery. An old friend was passing through Honolulu; a retired officer in the Royal Naval Hydrographic Service, with vast seagoing experience and a deep interest in navigation. I was looking forward to some enjoyable arguments (which I would of course win), but when I brought the subject up his response was, "Oh, yes," with a casually inclusive wave of the hand, "Zenith stars, and all that." No fun at all. Only later did I understand the reason.

Experienced navigators—especially those who know the Pacific Islands—know that the tropical ocean generally is a kind and predictable environment. They very likely will have read books or articles on non-instrumental navigation, such as those by Gladwin, Lewis, or Thomas. Modern navigators know the stars well enough to appreciate the potential for a much deeper (if non-mathematical) familiarity with the sky. The strategy of steering for large island groups rather than single islands is perfectly understandable, and even relatively untrained modern eyes can begin to use clouds and birds to detect land well over the horizon. Finally, though the native navigator could not have determined his east-west position at sea, his modern counterpart is well aware that Western explorers before Cook sailed all over the world under the same handicap. Of course the islanders could have done it—why not?

* Hokule'a is the Hawaiian name for Arcturus, which passes through the zenith on the island of Hawaii. "Hoku" equals star, and "le'a" equals happiness or pleasure; thus the name is commonly translated "Star of Gladness." The vowels have approximately the sounds they would have in Spanish, while the "apostrophe" is actually the symbol for the glottal stop (like the voice-break in the exclamation "oh-oh" in English).

At the same time, however, "zenith stars, and all that"* shows an imperfect appreciation of the problems which the native navigators had to overcome in the actual practice of their art. We have been developing this appreciation through the voyages of *Hokule'a*, giving an excellent illustration of the contribution which "experimental archaeology" can make to our understanding of the accomplishments of ancient peoples. In subjects as varied as shaping and use of stone-age implements, production of metals in primitive smelters, and navigation at sea with unaided senses, some things become evident only when one tries to repeat the process.

First Voyage, 1976

Ben Finney, in his book, *Hokule'a: The Way to Tahiti*, has described the story of the canoe from the first germ of an idea to the inception of the Polynesian Voyaging Society; the design, construction, and 1975 launching; and the successful 1976 voyage to Tahiti. Briefly, the 60-foot vessel was designed to replicate the performance of the Hawaiian voyaging double-canoes; in the absence of any models of the type, references of early observers had to be used to arrive at the shape of hull and rig. Practical considerations dictated the use of modern construction methods and materials. She can sail efficiently as close as 65 or 70 degrees to the true wind (a windward ability comparable to that of Captain Cook's square-rigged ships). It is easy to balance the sails for self-steering to windward, with a leeway angle of about 10 degrees (a surprise to some modern sailors who seem to expect a boat without a keel to go sideways). She shares the common catamaran characteristic of being very slow to turn, and difficult to tack in a seaway; this is accentuated by the absence of a jib, which could be backed to force the bow around. When there is searoom, she is usually jibed rather than tacked. There is no provision for reefing, so she must lie to in strong winds, with the rig lowered to the deck. This is not a severe handicap in the generally moderate conditions of the trade-wind zones.

The sails are permanently bent to the spars, and the rig is raised, lowered, and trimmed without benefit of winches or blocks with sheaves. Steering on a broad reach or run, using the large center sweep, is hard work. She is thus a heavy boat to handle, and is usually not sailed without at least six husky bodies in the crew. Living conditions are exposed and primitive, but adequate for the tropics. At the same time, however, the 40-foot by 9-foot platform gives a surprising feeling of spaciousness compared to the cockpit of a modern sailing yacht. She is fast in a good breeze, with easy motion. Pleased surprise is a common first response of experienced yachtsmen to her overall performance.

The 1976 voyage showed what an important part *Hokule'a* was to play in another role, separate from the study of non-instrumental navigation: to act as a living symbol of a powerful reawakening of Hawaiian cultural pride. No better symbol could have been found; the Polynesians were clearly first of all peoples in open-ocean seafaring. The project was not prepared for the magnetism of this vision of the canoe, however, leading to conflicts with some of the original navigational goals. The TV documentary of the voyage by the National Geographic Society illustrated (some would say over-emphasized) these growing pains. Today the two aspects, cultural symbolism and scientific investigation, support each other harmoniously and productively through careful planning.

The 1976 voyage also introduced another feature that has proven to be of vital, ongoing importance to the project: the involvement of the Micronesian traditional navigator, Mau Piailug (Pee-eye-luke; see *Oceanus*, Vol. 28, No. 1, p 52). One of the last trained from childhood in the art, Mau is only too aware that it is vanishing in its last stronghold in the Caroline Islands. Within the past few years he has changed from his traditional practice, in which key navigational teachings are revealed only to a select few, to an open desire to have the story of his system published in Western books in order to preserve it. This is a difficult and deeply impressive transition for someone from a non-literate culture. (And I wonder whether there are not better words to use: at sea, it is Mau who can read, and the rest of us who are illiterate!)

The 1976 voyage to Tahiti showed that Mau's non-instrumental navigation was a system flexible enough to allow successful adaptation to routes and latitudes not included in his traditional training. There was little transfer of information on Mau's actual navigational procedures, however, and the return trip to Hawaii was made using modern celestial navigation. There was still much to be learned.

The key to that learning was already at hand: Nainoa

* A star which passes directly overhead of a location on Earth is called a Zenith Star for that place. By sailing north or south until the known zenith star for your destination passes directly overhead on its nightly path across the sky, you can be sure that you have reached the latitude of your goal. This star will, of course, also pass overhead everywhere else along the same parallel of latitude. Arcturus (*Hokule'a*), for example, is a zenith star for the Island of Hawaii, but also for the Chinese Island of Hainan, the Indian City of Bombay, and all other points on Earth with latitude 19 degrees North.

Latitude is thus easy to find, but the determination of east-west position—the so-called "longitude problem"—resisted the best efforts of Western mathematicians, astronomers, and instrument-makers for hundreds of years. Longitude cannot be directly determined by the unaided senses. Two methods became available at about the period of Captain Cook's major voyages: the invention of the marine chronometer to keep accurate time, and procedures for determining time independently from lunar observations.

Without ability to determine longitude, noninstrumental navigators use the same strategy as Westerners before Cook: aim deliberately well to one side of your target, so that when you reach the correct latitude there will be no question about which way to turn. After turning, sail along the latitude of your goal until it appears.

Photo by Will Kyselka

Mau Piailug

Thompson, a university student and part Hawaiian, was becoming fascinated by the voyages of his Polynesian heritage. As a crew member on *Hokule'a* during its return from Tahiti, his interest was strengthened. He embarked on a lengthy, self-directed program of academic and practical study, with the goal of actually navigating the canoe on an ocean voyage without instruments.

Second Voyage, 1980

Nainoa absorbed and organized a vast amount of information on meteorology, oceanography, and astronomy (but, deliberately, not modern celestial navigation). The planetarium at Honolulu's Bishop Museum, under Will Kyselka, was of special importance in his training. He was already an expert boatman and fisherman. The one class that was not available, of course, was "Theory and Practice of Non-Instrumental Navigation." It was perhaps inevitable that he ultimately went to Mau, and convinced him, by the depth and sincerity of Nainoa's own commitment, to return to Hawaii as Nainoa's tutor. The time was six months before a scheduled 1980 voyage of *Hokule'a* to Tahiti; the hope was to have Nainoa do all the navigating, with Mau acting as backup in case of trouble.

Hokule'a departed Hilo, Hawaii (approximately 19 degrees North), on 15 March, making first landfall near the western end of the Tuamotu Archipelago (15 degrees South) after 30 days at sea. Tahiti was sighted at dusk the following day. On the return, departure was taken from Tahiti (approximately 18 degrees South) on 13 May, with the 13,000-foot peak of Mauna Kea on the Island of Hawaii seen in silhouette at sunset on the 24th day at sea; Honolulu was reached two days later. Nainoa guided the vessel over both legs of the voyage without instruments, and without requiring Mau's assistance.

Nainoa's navigational observations and decisions were recorded en route, in a regular format, for later analysis. The canoe's actual track was followed using the ARGOS satellite system, courtesy of Dr. William Patzert (then at Scripps Institution of Oceanography, now with the National Aeronautics and Space Administration). The 1980 voyage coincided with a detailed oceanographic/meteorological study of the central equatorial Pacific, so that we have excellent information on winds and current boundaries during the period of the canoe's passage.

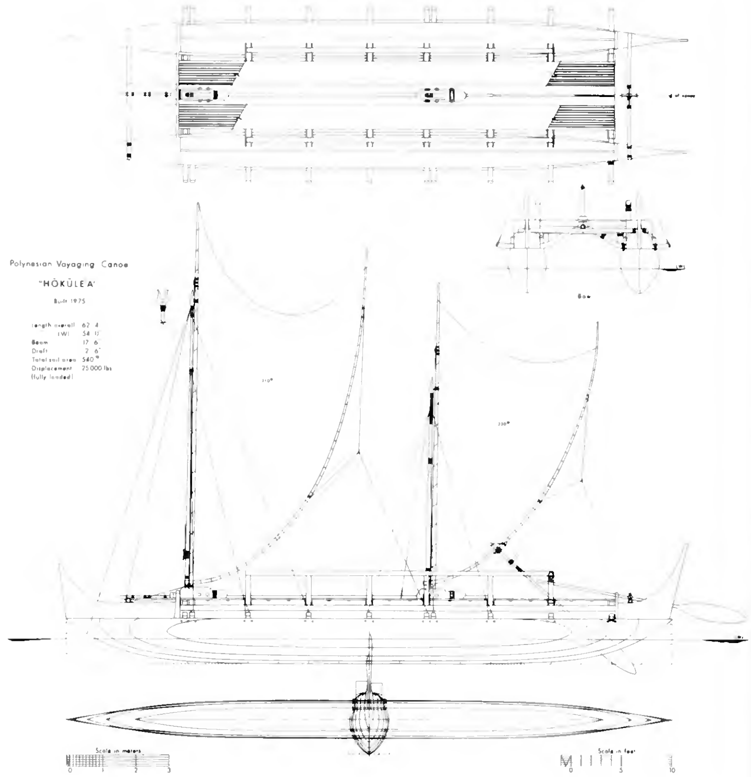
Photo by Will Kyselka

Nainoa Thompson

In general, the project was an unqualified success, but it has led to the strong realization that "zenith stars, and all that" misses some of the most interesting aspects of non-instrumental navigation. One of the most important of these was not well documented, because in planning for the voyage we were thinking of navigation primarily in terms of position and orientation; it's easy to forget that "non-instrumental" also means "no pencil and paper." The problem can be posed as a question: when navigation is being done entirely within one individual's mind, without plots or written records, what mental/physical practices allow him to stay aware of varying course and speed, and to maintain his reckoning, over a month-long voyage? (Part of the answer: the navigator stays alert, taking no more than brief catnaps, for the entire voyage. The extended mental discipline is impressive, to say the least.)

An important result of the project was its confirmation of our expectation that navigational errors tend to cancel, rather than accumulate, over a lengthy voyage. There is no consistent bias in the "star-compass," as there would be in an inaccurately compensated magnetic compass. As oceanographers are becoming ever more aware, ocean currents are variable over a wide range of scales, so that an underestimation of current in one area will almost inevitably be offset by overestimation elsewhere. Errors in individual estimates of latitude are largely nullified by the relatively large number of observations available; the navigator is not limited to morning and evening twilight, but can use stars all night long.

The results of our documentation of orientation and position determination can be summarized briefly:



DRAWN BY RICHARD RHODES 1/25/77

DIRECTION: Nainoa's star-compass is not identical to the traditional Carolinian compass (see references), but it is basically a parallel system. Direction is conceptually the easiest of the navigator's problems: the heading of the vessel can be determined as long as the sky is not obscured. At night the sky is filled with stars, and (given an intimate familiarity with the patterns wheeling from horizon to horizon!) orientation can be determined from any part of the star-field; it is not necessary that stars be visible directly ahead. During daylight, there is difficulty only when the sun is too high to use as an indicator of horizontal direction; for these few hours, each day, orientation is taken from wave patterns and/or wind (and the moon, if it is conveniently positioned).

Lengthy periods of totally overcast skies present a difficult problem, because (as with Lewis, Finney, and others before them) Nainoa finds that reading wave patterns for directional orientation is one of Mau's arts that cannot be learned quickly. It might be compared to the difficulty an untrained ear has in hearing the intertwined harmonic patterns in complex symphonic music. No amount of book-study can provide the skill; one has to listen to music—or, for waves, go to sea.

LATITUDE: Previous authors have strongly stressed the use of zenith stars (as my friend's "zenith stars, and all that" reflected), but in fact the zenith point is not easy to determine, even on land. Nainoa developed a system in which he memorized pairs of stars, each pair lying approximately on a single meridian. When such a pair stands upright it marks the observer's celestial meridian (and thus true North or South). He also memorized, for every pair, the angular separation between the stars, and the angle to the celestial pole (the "polar distance," or complement of the star's declination*). When an upright pair is observed, the angle between the horizon and

* The Declination of a star is its angular distance from the celestial equator, ranging from 0 degrees (the equator) to 90 degrees (the poles), North or South. Declination is thus the celestial equivalent of latitude on the Earth's surface.

either star can be estimated by comparing it with the known angle between the stars of the pair. This estimation can then easily be converted to latitude.

Note that the navigator is not limited to the bright "navigational stars" visible at twilight; he can work all night long, using star-pairs both to the north and the south as they wheel into position. Nainoa often used his hand, held out against the star-field, to aid his measurements of angle. He usually estimated latitude to the nearest degree, which is entirely adequate for making landfall in island groups that extend over several degrees of latitude.

It is obvious that ancient Polynesians did not have our concept of latitude, or of angular measurement as we know it. In effect, Nainoa's system allows him to use the sky without the decades of familiarity it would take merely to see, without measurement, when the upright Southern Cross (for example) has arrived at its proper height during a voyage. The Polynesian techniques have been lost, and we can never know how they used the stars, but the stars are the same. Nainoa's results show that unaided observation can allow latitude to be estimated adequately for deliberate voyaging.

The Hawaii-Tahiti route is largely north-south, so that latitude also gives a measure of progress along the track. The Carolinian *etak* system (see *Oceanus*, Vol. 28, No. 1, p 52) for calculating progress was not attempted. Although the *etak* system is easy to understand in principle, it is not at all clear how the estimates are made in practice; it would seem especially difficult to transfer this aspect of Carolinian navigation to regions outside of the traditional island group.

LONGITUDE: Properly, this should be titled "offset from the desired track," because true longitude cannot be determined. On the quasi-meridional Hawaii-Tahiti route, however, offset to left (east) or right (west) is essentially (and conveniently) equivalent to longitude.

Offset is the one factor, in this system of navigation, that can only be calculated by dead reckoning, and that must be maintained mentally throughout the voyage. On the relatively short voyages of Mau's home islands, each trip has a single known desired direction. If forced by winds to deviate from this, the navigator keeps track of each day's offset, adding to or subtracting from the total offset from the previous day. The offset reckoning is kept in terms of the estimated heading to the destination, rather than distance from the reference course (a Western concept).

For the Hawaii-Tahiti route, the different wind zones required different reference courses, with turning points at pre-selected latitudes. Nainoa mentally reduced each day's sailing to a single offset-increment to add to (or subtract from) the total offset carried over from the previous day. The offset was reckoned in units that were effectively equivalent to distance: one unit of offset would result from one "standard" day's sail of 120 miles (sailing speed 5 knots) in a direction one star-compass point off the reference course. It sometimes took Nainoa 45 minutes of intense, solitary thought (no pencil or paper allowed!), at the end of a day during which the winds forced the canoe to sail at various speeds and directions, to arrive at a figure he felt was reasonably secure.

LANDFALL: As expected, the observational skills of the "primitive" islander, Mau, were by far the most sophisticated on the canoe. There is no substitute for a lifetime of watching the behavior of seabirds, or the formations of clouds, or the patterns of waves. Mau's help was openly sought, at this point in the southbound voyage; it was clear from the increasing numbers of birds that landfall was imminent, and good seamanship dictated the earliest possible detection of the dangerous reefs typical of the Tuamotu atolls.

Third Voyage, 1985–87

At this writing (mid-July), *Hokule'a* is just under way on an ambitious new project called the "Voyage of Rediscovery." Cultural aspects play a large part in the plans, which will take the canoe through Polynesia on a voyage lasting 27 months. Nainoa Thompson is again the navigator, and Mau Piailug (who clearly loves to go sailing!) has come once more to Hawaii to join his student on the canoe. Nainoa's work will be documented essentially as before.

As planned, the voyage will include nine different segments, with stops at various ports for crew transfer, overhaul, and waits for proper seasonal wind conditions. We expect the project to result in a significant increase in our understanding of the potentials (and limitations) of non-instrumental navigation, because the various legs of the voyage will present the navigator with very different problems to solve:

HAWAII–TAHITI: The first leg of

the voyage was successfully completed while this article was in preparation. As expected, it was very much like the two previous Hawaii–Tahiti trips, with climatological differences resulting from the later departure (10 July, compared to 1 May 1976, and 15 March 1980). The season of northern-hemisphere tropical disturbances had begun, requiring a careful watch; hurricane Ignacio was intensifying far to the east as the trip got under way, but the canoe made good speed southward across the Northeast tradewind zone, so that the storm crossed its track safely astern.

Another consequence of the late start was that the doldrum belt north of the equator was more fully developed than on the previous trips, and difficult to work through under sail. There were many more totally overcast days than on the 1980 crossing, forcing Nainoa to practice the difficult art of direction-orientation from wave and swell patterns. The winds south of the equator were stronger than during the previous trip, however, and landfall in the western Tuamotus was made on the 31st day at sea (the passage took 30 days in 1980 and 31 days in 1976). Tahiti was reached the following day, 11 August.

It is remarkable that all three voyages made landfall in the Tuamotus within 60 miles of each other, despite differing wind conditions, and after navigating for more than 2,000 miles without instruments.

The Challenges of Canoe Life

Voyaging on Hōkūle'a *has a cycle of high and low moments. The canoe platform is 40 feet by 9 feet. One shares this platform with 11 other people.*

One brings aboard only what one can carry in a bucket. So you have little that is your own. There is no place to be alone. You are constantly exposed to the winds, waves and the burning sun.

Food and water must last through the entire voyage. Since the length of the voyage is not totally predictable, what you can eat and drink is restricted.

Dr. Benjamin Young, of the University of Hawaii School of Medicine, sailed on Hōkūle'a, *systematically observing the challenges of canoe life.*

"You have to learn well this sense of survival," Young wrote, "for it was this sense of survival that enabled our ancestors to make long voyages from Tahiti to Hawaii. Try and change your habits of eating and drinking, and you will see that it can make you very irritable."

Also, Young wrote, "You must learn to be patient and tolerant even of small things. Snoring, failing to brush your teeth, even not getting up on time can be irritating to others. The crew must be able to work together, and each crew member must be tolerant of the personalities and habits of others."

"Though a voyage on a double-hulled canoe appears exciting, many days are routine and monotonous." Boredom is a real challenge. "To fight the effects of boredom, your mind and hands should be kept busy. Reading books, carving wood, playing instruments, and singing songs help keep you from being bored."

A sense of danger is always present. "One always anticipates danger on a voyage, but once the voyage begins, the tensions lessen."

TAHITI–COOK ISLANDS: This is a relatively short leg, in which the emphasis will be on the ability to steer an accurate downwind course. This leg is more nearly east-west than north-south in direction, so that the navigator will not be able to depend on latitude measurement to give an indication of forward progress. Dead reckoning estimates of distance run will thus become much more important than before. Mau's land-finding skills will come into play when the canoe gets among the widely scattered islands of the Cook group.

COOK ISLANDS–NEW ZEALAND: The traditional cultural ties between the Maoris of New Zealand and the Hawaiians and central Polynesians are of deep importance, and are a primary factor motivating this part of the voyage. The navigational problems on this leg will largely result from the relatively high southern latitudes, with unfamiliar star orientations and weather sequences, including the possibility of overcast conditions. The target is big, but the likelihood of adverse weather is all too real.

NEW ZEALAND–TONGA: This leg does not correspond to any traditional Polynesian route, so that it is simply a matter of ferrying the canoe north into western central Polynesia as efficiently as possible. Modern navigation may be used to aid landfall in dangerously reef-infested waters.

TONGA–SAMOA: The winds may make this a difficult upwind sail, but the high islands of Samoa are the logical starting point for the following segment of the voyage. Inhabited for more than 2,500 years, Samoa is considered the "cradle of Polynesia."

SAMOA–COOK ISLANDS: Probaby the most difficult leg: an extended upwind beat against the Southeast trades. The long tacks will be a severe test of the dead reckoning aspects of non-instrumental navigation. It may well be that the ancient voyagers waited for the well-developed westerlies of what we now know as *El Niño* years. The results of *Hokule'a*'s effort should provide material for discussion on this point.

COOK ISLANDS–TAHITI: Another windward sail, but over a shorter distance. There is ample evidence that, at the time of Western discovery, the Tahitian navigators were well acquainted with the Cook group, indicating that two-way voyages were not infrequent.

TAHITI–MARQUESAS: The first migrations to Hawaii, about 500 A.D., came from the Marquesas, lending cultural significance to this stopping point. The principal navigational problems will come from the necessity of working upwind in the trades after sailing north of the Tuamotu Archipelago.

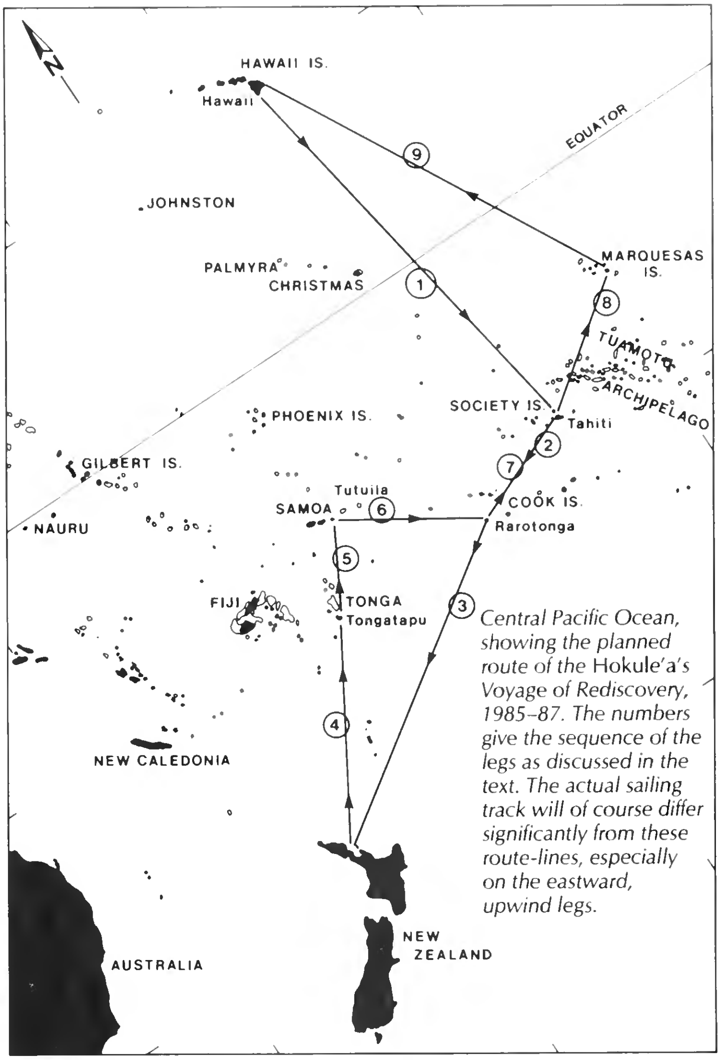
MARQUESAS–HAWAII: The homeward-bound leg will be the easiest; the canoe will be starting well to windward, allowing her to head north across the trades on a fast reach for some 1,700 miles, bearing off to run before the wind when the latitude of Hawaii is attained.

Full Respect for Skills

In addition to the documentation of the navigation itself, there will be extensive documentation of all other aspects of the voyage for widespread public information and educational use. The canoe, together with exhibits on Polynesian migrations, traditional navigation, and so on, will become permanent features of a maritime museum being developed at Honolulu Harbor.

Experimental sailing by itself can prove, or disprove, very little regarding Polynesian migration theory. With luck, it is possible to sail from anywhere to almost anywhere else, in almost any kind of boat; fools get away with it every year. Without luck, even large, well-found vessels with experienced crews are lost. Theory must be based on findings in such fields as archaeology, anthropology, and linguistics. Only experimental voyaging, however, can bring us full respect for the level of observational and practical skills of the early Polynesian master seafarers.

Edward D. Stroup is a physical oceanographer with the Department of Oceanography, University of Hawaii at Manoa. Born in Honolulu, he has long been interested both in the history of sail and in Hawaiian language and culture. He has been involved with the Hokule'a's voyages since 1979, and is currently one of the Directors of the Polynesian Voyaging Society and heads the Society's navigation research committee.



Central Pacific Ocean, showing the planned route of the Hokule'a's Voyage of Rediscovery, 1985–87. The numbers give the sequence of the legs as discussed in the text. The actual sailing track will of course differ significantly from these route-lines, especially on the eastward, upwind legs.

Notes:

The Polynesian Voyaging Society is a non-profit, tax-exempt, volunteer-based organization devoted to the study of the voyaging heritage of the peoples of Polynesia, and to disseminating the knowledge gained through publications and educational programs. Much of the Society's work involves its "research vessel," the 60-foot *Hokule'a*, the only existing performance-replica of an Hawaiian ocean voyaging canoe. The current "Voyage of Rediscovery," with a budget of more than $1 million, is being supported by the State of Hawaii, by grants, and by individual memberships and corporate donations. New members are welcome; for applications or information write to: Polynesian Voyaging Society, P.O. Box 19000-A, Honolulu, Hawaii 96819.

References

Duncan, Leith. 1982. Experimental Voyaging in the Pacific. *J. Polynesian Soc.* 91(3): 455–465.

Finney, Ben R. 1979. *Hokule'a: The Way to Tahiti.* 310 pp. New York: Dodd, Mead & Company.

Finney, Ben R., Bernard J. Kilonsky, Stephen Somsen and Edward D. Stroup. 1985 (in press). Re-Learning a Vanishing Art. *Journal of the Polynesian Society*, Aukland, New Zealand.

Gladwin, Thomas. 1970. *East is a Big Bird: Navigation and Logic on Puluwat Atoll.* 241 pp. Cambridge, Mass.: Harvard University Press.

Lewis, David. 1972. *We, the Navigators.* 345 pp. Honolulu, The University Press of Hawaii.

Thomas, Stephen D. 1985. The Sons of Palulap: Navigating Without Instruments in Oceania. *Oceanus*, 28(1): 52–58.

Whaling, Conservation, and Diplomacy

Since its inception in 1948, the International Whaling Commission (IWC) has been a magnet for controversy; this last year has been no exception. The decision by the Japanese government to allow the harvest of sperm whales in the 1984–85 season despite an IWC ban, but with the approval of the American government, has led to a complicated legal battle between American conservationist groups and their federal government. The conservationists are demanding that the government impose economic sanctions against Japan to enforce the IWC ban. The results of this conflict, recently aired in federal court, will influence worldwide policy and attitudes toward whaling.

A humpback whale breaching off Cape Cod. After being declared a "protected stock" by the IWC, this species recovered from the edge of extinction. (Photo by Anne Rabushka)

A Little History

Formed originally by whaling nations, the IWC* was given two conflicting goals: rational management of whales as a resource and consideration of the best interests of the whaling industry. Ideally, all whaling nations, regardless of the size of their industry, as well as non-whaling nations with an interest in the resource, should be members of the IWC. Guidelines for the IWC are contained within the International Convention for the Regulation of Whaling (ICRW). Although the ICRW is a permanent document, its Schedule, which contains regulatory provisions such as quotas and seasonal restrictions, is flexible and may be amended.

The IWC meets annually to discuss progress in the whaling industry and new scientific information in order to update the Schedule. A three-quarters majority is needed for the passage of any amendment. If dissatisfied with an IWC decision, a member nation may make a formal objection within 90 days, in which case it will not apply to that government, nor does the previous Schedule apply. Alternatively, a nation could withdraw, an undesirable option since the IWC would no longer have any influence on that nation's whaling activities.

During the first two decades of its existence the IWC was not successful in managing whale stocks. The strong influence of the whaling industry allowed too much consideration of short-term economic gain without long-term consideration of the stocks; quotas were generally set far higher than the recommendations of the IWC's Scientific Committee. This eventually led to the collapse of Antarctic whaling in the mid-1960s because of drastically reduced stocks. This collapse

* Norway, the United Kingdom, and the United States were the founding nations. By 1985, the 38 additional member nations are Antigua and Barbuda, Argentina, Australia, Belize, Brazil, Chile, the People's Republic of China, Costa Rica, Denmark, Egypt, Finland, France, the Federal Republic of Germany, Iceland, India, Ireland, Japan, Kenya, the Republic of Korea, Mauritius, Mexico, Monaco, the Netherlands, New Zealand, Oman, Peru, the Philippines, Saint Lucia, Saint Vincent and the Grenadines, Senegal, the Seychelles, the Solomon Islands, South Africa, Spain, Sweden, Switzerland, the Soviet Union, and Uruguay.

compelled whaling nations to understand the necessity of effective conservation measures. In 1965, drastic quota reductions were accepted without objection.

In the 1970s, amendments were made that, combined with these quota reductions, greatly improved the IWC's ability to manage whales rationally. For example, it was recognized that certain whale species are subdivided into several distinct stocks that probably do not interbreed; these stocks were given separate quotas. Another improvement was the International Observer Scheme whereby whaling activities of each nation could be monitored by other member nations. These reforms were encouraged by a small, but strong, conservationist bloc within the IWC, led by the United States and Australia. In the early 1980s, this conservationist bloc called for membership of many non-whaling countries; by 1982, among the 39 IWC members, conservationists outnumbered whalers by more than two to one. This change in composition has refocused the IWC's mission from resource management and consideration of industry's interests to conservation of whales through the cessation of whaling.

Since 1973, various proposals for a global moratorium on whaling have been made and abandoned. In 1982, a proposal was accepted to phase out commercial whaling over a period of three years and to set zero-catch limits on all stocks of whales for the 1985–86 Antarctic season and the 1986 season elsewhere. Japan, the Soviet Union, Norway, and Peru submitted formal objections within the prescribed 90 days (which exempted them from compliance), although Peru withdrew its objection in 1983.

The 1982 moratorium agreement has within it a mandate that the IWC must do a comprehensive review of the effects of the ban after five years, that is no later than 1990. If stocks seem able to support catches, then the IWC may recommend resumption of whaling. But resumption of whaling is unlikely given the current membership of the IWC and the three-quarter majority vote needed to alter the Schedule. Even if whaling were allowed again, it is doubtful that the industry would be able to pick up again after a five-year halt; most whaling ships would have found alternative uses by then.

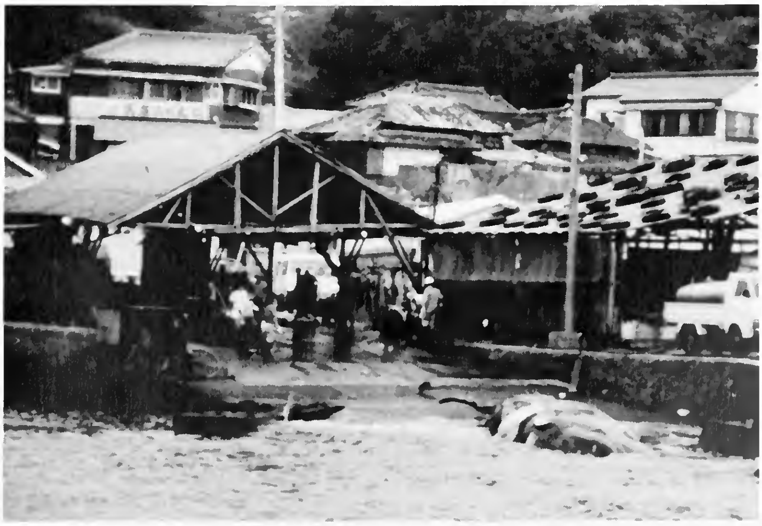
Economic Sanctions

As with all other international fishery commissions, the IWC has no power to enforce its regulations. The United States Congress has passed two domestic laws to encourage compliance with international fishery agreements through the threat of economic sanctions. The Pelly Amendment, a 1971 addition to the Fisherman's Protective Act, and the Packwood-Magnuson Amendment, a 1979 addition to the Fishery Conservation and Management Act, provide punitive measures to be applied to a nation that "diminishes the effectiveness" of international fishery conservation programs in which the United States participates. The Pelly Amendment can be used to support any such fishery conservation program and allows the United States to embargo fish or fish products coming from an offending country. The Packwood-Magnuson Amendment deals specifically with whaling. It calls for a nation "certified" by the Secretary of Commerce as diminishing the effectiveness of the ICRW to have its fishery allocation within the American 200-mile Exclusive Economic Zone reduced by at least 50 percent.

The Packwood-Magnuson Amendment is considered a powerful means of coercion with respect to IWC rulings because the two largest whaling nations, Japan and the Soviet Union, have substantial fisheries within American waters (330,000 and 44,000 tons per year, respectively). Supporters of the moratorium on commercial whaling depend heavily on the threat of these economic sanctions. However, in the autumn of 1984, the American government chose to make a bilateral agreement with the Japanese rather than impose sanctions.

Controversy

On November 4, 1984, Japan began its North Pacific sperm whaling season despite the fact that the stock was unclassified and no quota had been set. A 1981 ban on the catching of sperm whales exempted the North Pacific western division stock of sperm whales, but no



The carcass of a sperm whale being hauled out of the water in Wadaura, Japan, last fall. When Japan continued to take sperm whales despite an IWC ban, it touched off a legal battle in the United States with international repercussions.

whales were to be taken until enough scientific information was gathered that quotas could be agreed on each year. Japan had lodged a formal objection to these decisions, and was thereby acting within the rules of the IWC, but concerned conservationist groups outside of the IWC considered it to be violating an IWC ban and thus diminishing the effectiveness of the ICRW. These conservationists thought that this was an opportunity for the Packwood-Magnuson Amendment to be put into action for the first time and expected economic sanctions to be imposed.

Meanwhile, the U.S. Departments of State and Commerce were involved in delicate negotiations with Japan, a major trading partner. The avoidance of economic sanctions against Japan would benefit these other trade negotiations. On November 13, 1984, a bilateral agreement was concluded in which the United States agreed not to impose economic sanctions if the Japanese would withdraw their objection to the sperm whale bans by December 13, 1984, and to the moratorium by April 1, 1985. The American government reasoned that if the Japanese retracted these objections it would no longer be diminishing the IWC's effectiveness and would therefore not be subject to the Packwood-Magnuson Amendment.

Anticipating such an agreement, 12 American environmental and animal-welfare organizations,* as well as one individual, Thomas Garrett (a consultant for the wildlife department of Greenpeace), filed a lawsuit against the Secretary of Commerce and the Secretary of State on November 8, 1984. The Japanese Whaling Association and the Japanese Fisheries Association joined the suit as defendant-intervenors. The conservationists think the law clearly obliges the government to certify Japan and to reduce fishery allocations. They contend there is no provision to allow either of the secretaries any discretion to make alternative deals.

The U.S. District Court for the District of Columbia agreed with the conservationists. On March 5, 1985, Judge Charles R. Richey ruled in favor of the plaintiffs and ordered the American government to impose the sanctions against Japan. "It appears a complete reversal for the Secretary of Commerce to agree not to certify a foreign nation whose nationals are intentionally whaling in violation of established IWC quotas," he ruled. The U.S. Justice Department, however, immediately appealed this ruling, which postponed the imposition of the economic sanctions. Hearings were held in the Federal Court of Appeals for the District of Columbia on May 16, 1985.

As for Japan's end of the deal, on December 11, 1984, Japan withdrew its objection to the sperm whale ban, effective in 1988. The bilateral agreement allows them to take up to 400 sperm whales in each of the 1984 and 1985 coastal seasons without the imposition of sanctions by the United States. The Scientific Committee of the IWC has stated that such a small catch should have no deleterious effects on the stock.

The second part of the arrangement provided that if Japan would withdraw its objection to the commercial whaling moratorium, they would be allowed to take up to 200 sperm whales in each of the 1986 and 1987 coastal seasons and other whales as well, using the most recent IWC quota for each stock as a guideline, through to the end of the 1986–87 pelagic season and the 1987 coastal season. These conditions were acceptable to the U.S. government. In a letter sent to the U.S. Secretary of Commerce on April 5, 1985, the Japanese government agreed to withdraw its objection to the moratorium (to be effective in 1988), but the withdrawal is conditional; it will be made only if the American government ultimately wins the court case and thus does not have to impose sanctions against Japan.

It might seem that the conservationists will win either way. If the conservationists ultimately win the court case, sanctions will be imposed and the Japanese are expected to stop sperm whaling in order to have the sanctions lifted, since their fishery in American waters is worth between $200 million and $500 million annually, compared with the approximately $5 million that 400 sperm whales are worth. If they lose the case, the Japanese will stop sperm whaling and accept the moratorium.

A closer look reveals that if the conservationists lose their case, neither sperm whaling nor other commercial whaling will stop until 1988; if they win, whaling might stop this year. Furthermore the conditional agreement made by the Japanese may not be binding under international law. Even if it is, some suspect that the Japanese will find loopholes somewhere and continue whaling, perhaps under the guise of research whaling or aboriginal/subsistence whaling, activities not prevented by the moratorium. Most importantly, however, the conservationists feel that if they lose their case, the power of the Packwood-Magnuson Amendment, and therefore that of the IWC, will have been undermined, and the only chance of enforcing the moratorium lost.

The American government does not seem to feel that the Packwood-Magnuson Amendment has lost its credibility or power. In the interim between the lower and upper court hearings on the Japanese situation, the Secretary of Commerce certified the Soviet Union under the Packwood-Magnuson Amendment for exceeding the allowable catch of minke whales in the Antarctic. Their allocation of fish in American waters was reduced by half shortly thereafter.

At this year's annual IWC meeting, the Soviet Union announced that by 1988 it would cease Antarctic whaling, its only commercial whaling.

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* American Cetacean Society, Animal Protection Institute of America, Animal Welfare Institute, Center for Environmental Education, Connecticut Cetacean Society, Defenders of Wildlife, Friends of the Earth, The Fund for Animals, Greenpeace U.S.A., The Humane Society of the United States, International Fund for Animal Welfare, and The Whale Center.

Conservationists claim that the main reason for this move was the imposition of these economic sanctions. According to The New York Times, however, the Soviet Commissioner, Ivan Nikonorov, denounced the United States for the sanctions and cited declining stocks as their impetus. Regardless of the reason behind the Soviets' delayed acceptance of the moratorium, it fits in neatly with Japan's proposed cessation of whaling in 1988.

The status of the North Pacific stock of sperm whales was reviewed at the annual meeting and it was voted that this stock become classified as a "Protection Stock" in 1988. This automatically and unambiguously sets the catch limit at zero. This also fits in with Japan's proposal. It seems as though IWC members have accepted that the commercial moratorium will not really go into effect until 1988. As Thomas Garrett observed, "It was as if everyone at the IWC meeting expected us [the conservationists] to lose our law suit."

Results of the Appeal

On August 6, 1985 the Court of Appeals presented its decision. Once more, the courts ruled in favor of the conservationists, in this case by a vote of two to one. Whaling by the Japanese despite the IWC ban was considered to be an obvious diminishment of the effectiveness of the IWC and the Secretaries of Commerce and State have been ordered to certify Japan and reduce Japanese fishery allocations within 90 days. The government may further postpone the imposition of economic sanctions by continuing the legal battle; they could request that the case be heard by the full Appellate Court, ten judges instead of three, or they could take the case to Supreme Court.

Whether the government will admit defeat or continue to fight remains to be seen. It does not appear that the IWC is gravely threatened, regardless of the outcome. The Japanese have already irrevocably withdrawn their objection to the sperm whale ban. Although their sperm whaling might not cease until 1988, the Japanese would be taking these whales at levels deemed by the IWC itself not to be harmful to the stock.

If, in the end, the American government finally wins its case, then the Japanese have agreed to cease commercial whaling by 1988, a date that converges with other agreements to end whaling made at this year's annual IWC meeting. If the Japanese try to find loopholes and continue to whale despite this agreement, then the American government will still have the option of imposing sanctions through the Packwood-Magnuson Amendment.

The conservationists fear that the power of the Packwood-Magnuson Amendment has been lessened by the fact that it was not immediately invoked against the Japanese; however, the amendment's threat of the economic sanctions was an important leverage point for the Americans when making the bilateral agreement. By this agreement, Japan, the world's foremost whaling nation, has made a commitment to the IWC's overall whale conservation program. In the bargain, the United States has tried to avoid punishing Japanese fishermen for the actions of Japanese whalers, and has also tried to prevent American fishermen from losing profitable joint fishing ventures with the Japanese.

On the other hand, if the decision of the Court of Appeals is upheld, the implications seem less clear. Certainly, the conservationists will have chalked up a victory and will have clarified how the Packwood-Magnuson Amendment is to be used. Once economic sanctions are imposed against the Japanese, their subsequent reactions are not clear. As stated earlier, it is likely that they will stop sperm whaling in order to lift the sanctions, but how will they treat the commercial moratorium? Could the IWC's goal of a cessation of whaling actually be damaged by imposing the sanctions? Or will the Packwood-Magnuson Amendment come to the rescue again? As for American interests, will trade negotiations become endangered, leading to a trade war between Japan and the United States? The Los Angeles Times reported that a spokesman for the Japanese Whaling Association has said that Tokyo may threaten to block sales of hundreds of millions of dollars' worth of American fish to Japanese canneries, in the hopes that U.S. legislators will alter the law to permit Japan to continue whaling until 1988.

What is clear is that this is a complex issue. No solution will be satisfactory to all who are directly or indirectly linked to whaling. With the upcoming moratorium, the IWC will be going through a difficult period of transition; some flexibility is going to be necessary to ensure continued success in the protection of whales.

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Acknowledgment

The author would like to thank Susan B. Peterson of Boston University for her support and help with this manuscript.

Letters

To the Editor:

I have read with interest your Summer, 1985, issue of *Oceanus*. However, I am somewhat concerned with the carrier as the nucleus of the Navy's fighting force.

The carrier appears to be an anachronism in today's world. It was a fine weapon when the most accurate missiles were the V1 and V2 rockets. Now, though, missiles such as the MX can travel 6,000 miles with an accuracy of 300 feet. Other extremely accurate and powerful missiles being developed and improved each year would seem to test the limits of the lastingness of the carrier. Also, in modern aerial combat the entire carrier complement of planes possibly would not survive a week of war.

It would seem that under these conditions there is now a need for small, high endurance ships carrying a limited number of jump jet fighters and helicopters.

The focal point of the task force should now be the submarine shown on your front cover. This ship, nevertheless, also has a limitation. It pollutes the oceans with radioactive slime that is apparent on the hull when it returns from an extended deployment. To minimize this contamination the time at sea for these craft should be limited. This can be done by constructing berths from which these vessels can leave and return without surfacing. Thus, only a few would know when they were at sea.

Thomas A. Bender, Jr.
Rochester, Minnesota

To the Editor:

I can read about war dreams in many other publications. I am dismayed to see that *Oceanus*, like WHOI [the Woods Hole Oceanographic Institution], has "enlisted" with the current wave of military mania. The back cover of your recent issue (The Trident launch) is a *nightmare*.

Jeffrey Karson,
Associate Scientist,
Geology and Geophysics Department,
Woods Hole Oceanographic Institution

To the Editor:

I read Pat Masters article (*Oceanus*, Vol. 28, No. 1, p. 27). It deals with material that I have spent about 60 years studying. I find it disappointing. Pat would not be surprised, for she knows that I consider that the evidence indicates the presence of man in the area for a sizeable multiple of the time that she indicates. An article on Southern California archaeology that mentions only one source: Shumway, Hubbs, and Moriarty, is a bit wierd (see *Pleistocene Man at San Diego*, The Johns Hopkins University Press, Baltimore, 1957. Or, more readable, *Earlier Than You Think*, the Texas A&M University Press, 1980, by me).

George F. Carter
Ellsworth, Maine

To the Editor:

". . . I have read with great interest the article "The 1984 Argentine-Chilean Pact of Peace and Friendship" written by Michael A. Morris, published in the magazine "*Oceanus*", Vol. 28, No. 2, Summer 1985.

On this matter I must express that, in my opinion, said article has some subjective remarks, erroneous appreciations and inconsistent omissions. . . .The . . . article is unfair [to] my country [for] the following reasons:

First, considering that it was not . . . mentioned, I must point out that Chile has never failed to respect treaties, international law, and the pacific settlement of controversies. . . .This has been a traditional course of action of our foreign relations.

On the other hand, the 1881 Treaty between Chile and Argentina is not as ambiguous and uncertain as . . . indicated. . . .The judgement of five members of the International Court of Justice, whose award was endorsed by Her British Majesty in 1978, allowed . . . the rights that Chile has on the Eastern approach to the Beagle Channel and also the lack of legal basis for the arguments held by Argentina.

At the same time, from the second article of the 1881 Treaty between Chile and Argentina and also from the diplomatic history which led us to the signature of this Treaty, it is possible to determine the sovereignty of Chile over the whole Strait of Magellan. Now, the new 1984 Treaty has come to assign to Argentina the waters out of this Strait, east of the border line fixed between Dungeness and Espíritu Santo.

Also, this article only points out the Argentine efforts to attain a pacific outcome by means of President Alfonsín. Undoubtedly, he deserves to be mentioned, but it our efforts should not be forgotten during a long and continued period in which Chile never discouraged diplomatic negotiations.

Besides, both countries appear to have embarked during many years in a stubborn and exorbitant arms race, but in fact it has been internationally known that during its military government (1976–1982) Argentina purchased over $15 billion in weapons, breaking all records, and being the only one responsible for such an arms race as its instigator. This was demonstrated on April 2, 1982, when Argentina made use of force to occupy the Falkland Islands, making the whole region unstable due to the political effects it brought about in the frame of the Inter-American Treaty of Reciprocal Assistance (IATRA).

Finally, the author has disqualified in advance the new 1984 Treaty, stating that it is difficult to be optimistic about the relations between both countries and that their conflict resolution measures may fail to function in practice. Also, he considers that its articles from 7 to 9 specify complicated provisions related to maritime delimitations, but he does not indicate the reason on which he bases his [apprehensions] or the motives he has had in mind, therefore contributing to the spread of confusion or hopelessness with respect to the future implementation of the 1984 Treaty and indirectly fostering the conflict. . .

José T. Merino,
Admiral,
Commander-in-Chief, Chilean Navy,
Santiago, Chile

To the Editor:

I recently received a copy of your Spring 1985 issue devoted to Marine Archaeology (Volume 28, Number 1). It is a significant contribution to the literature of the field.

George R. Fischer,
Advisory Council on Underwater Archaeology,
Tallahassee, Florida

To the Editor:

In January, 1985, the Marine Hydrophysical Institute of the Ukrainian SSR Academy of Sciences started publishing the *Marine Hydrophysical Journal*. It is intended for oceanologists, geophysicists, and scientists engaged in the construction of marine instruments, as well as space oceanology. It also might be of use [to] instructors, post-graduates, and students of specialities.

The journal has three main sections. *Thermohydrodynamics of the Ocean*: this section includes theoretical articles and reviews that present global models as well as models of isolated oceanic processes and mechanisms.

Analysis of Observations and Calculational Methods for Hydrophysical Fields in the Ocean: this section contains articles of general interest and data interpretation, as well as applied methods for calculation of oceanographic characteristics.

Experimental and Expedition Research: this section highlights articles on conducted studies and oceanologic experiments.

Supplementary sections will deal with research in space hydrophysics, automation of scientific studies, and modelling of marine systems.

For further information, please write to: *Marine Hydrophysical Journal*, 28 Lenin street, Sevastopol, 335000, USSR, tel. 25376.

Boris A. Nelepo,
Editor-in-Chief,
Marine Hydrophysical Journal,
Sevastopol, USSR

To the Editor:

I am a photographer and neighbor and this letter is about decisions that I, for one, find very difficult.

You've been seeing the magazine advertisements for years; 4×4's and motorcycles hurtling over beachgrass and bathers. Damn the endangered species, full speed ahead. And what about those Marlboro ads, the pride of the industry? The original campaign for the cigarette was aimed at women. When it didn't sell, the "Marlboro Man" saved the day.

As a professional photographer these "print ads" present me with dilemmas. Usually ads are drawn by an art director and approved by the client. Then the photographer tries to match the drawing. Would I, on some not so unlikely future job, mention to the people paying me that I don't think we should encourage people to drive recklessly anywhere they please?

The Marlboro ads are a photographer's dream. Groups of cowboys and photographers are turned loose for weeks at a time on Wyoming dude ranches. Unlimited budgets, no drawings to imitate—the photographers are free to shoot. Unfortunately, I believe advertising works and I believe cigarette smoking is "hazardous to your health."

Another category of ads that support many photographers is for military hardware. Helicopters, tanks, ships; they pay very well. (One photographer I used to assist was photographing an ad for Northrop when two of the jet fighters collided. Though the planned ads might have paid better, the photos ran as a center spread in *Life*.)

RCA is currently doing a big campaign for "Aegis"* and includes mention of RCA's work on the Ground Wave Emergency Network, GWEN, which will "provide survivable communications throughout the United States in case of national emergency."** Since the system is specifically designed to resist the electromagnetic pulse of nuclear detonations, it is reassuring to know that although we may not survive the "national emergency," our communications will. The advertisement is illustrated with what appears to be a composite of airbrushing and photos. If this system is vital, why does it need advertising? I would not take photographs for such ads.

But for me, that is a relatively simple decision. All I stand to lose is money—not that that wouldn't hurt. But it has never been my ambition to be the best darned armaments photographer around. For many of you who must find funding for projects you care about, such decisions must be very difficult indeed.

In the foreword to the book "Last Aid" by International Physicians for the Prevention of Nuclear War, Dr. Lewis Thomas calls on what he calls "the profession of arms" to read the book—which details the unacceptable consequences of nuclear war—and work to "give up nuclear weapons of all kinds and to make sure that such devices for humankind's suicide are forever abandoned."

But Dr. Thomas here raises two questions; what is "the profession of arms" and what are "nuclear weapons of all kinds?"

In my own field, I was surprised to learn that the Pentagon produces more movies than Hollywood. The Army, Navy, and Air Force each maintain public libraries with over a million slides.

In fact, the defense industry is second only to agriculture in the number it employs. Considering the extensive interchange of personnel (including Caspar Weinberger and George Shultz) between corporations and the military, and with civilian consulting firms and

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* The U.S. Navy's anti-air warfare weapon system.
** *Science 85*, May 1985, Pg. 84–85

universities advising the military on strategy as well as technology, the profession of arms is no longer defined by uniforms.

As for the second question, now that soldiers can carry nuclear backpacks, even humans can now be considered viable delivery vehicles. Land mines and depth charges can be atomic; tanks, naval and field artillery—in fact roughly 80 percent of our so called conventional forces—are "nuclear capable." The distinction between nuclear and conventional weapons is at best difficult to define.

In his January 17, 1961, farewell address, President Eisenhower made his well known warning of "the acquisition of unwarranted influence ... by the military-industrial complex." Later in that speech he said: "In that same fashion, the free university, historically the fountainhead of free ideas and scientific discovery, has experienced a revolution in the conduct of research. Partly because of the huge costs involved, a government contract becomes virtually a substitute for intellectual curiosity." Since large budgets are easiest to justify when they involve defense, projects seem to bend, like heliotropic plants to the sun, toward military applicability.

Also like the plants, there is competition. Funding, as you know, is actively sought. The Department of Defense does not force contracts on unwilling corporations. The B-1 bomber is being more effectively pushed by Rockwell than the Pentagon. Livermore Labs lobbied to build the H-bomb.

And this, at last, is my point. We are the profession of arms; we are the ones who must work to give up nuclear weapons of all kinds. Responsibility for the over-emphasis of the "military-industrial complex" that Eisenhower warned against, should include those who seek the funds as well as those who seek the results of that funding.

I realize that the assumption of this responsibility has serious implications for the Woods Hole Oceanographic Institution (WHOI). In your annual report, I see that about a fourth of your funding comes from the Office of Naval Research (ONR). I have heard rumors that the Navy wants to introduce a Masters program at WHOI. And in "The Cape Cod Times" I read that the cost of badly needed new ships is to be split between the National Science Foundation and ONR.

Of course, if the research is truly basic, it shouldn't matter who is paying. But since passage of the Mansfield amendment in 1969, the ONR is not supposed to fund anything that cannot be shown to have direct military application.

The obvious guess for a layman is that such projects as the "rapid deployment" of remote sensing telemetric buoys applies to submarine warfare and represents a valuable tool bending toward the ONR light. I feel it is a terrible waste when WHOI's minds and facilities are diverted to things that must not be used. World War II showed that almost any research can trickle down to military use, but the real waste comes when society's needs must trickle from the military. Research on ocean currents may help find food sources or submarines. I think the food should come first.

Nuclear strategy is no longer a matter of simple deterrence (if so, we wouldn't be trying so hard to find their submarines or worrying about post-attack communications). The Strategic Defense Initiative could put the arms race into overdrive. Unless it is a perfect system, each side will build enough missiles to assure that if, for instance, only 5 percent of their missiles will get through, that that 5 percent is an adequate deterrent. The MX decision indicates that the 50,000 nuclear weapons in the current world arsenal are apparently not perceived as an adequate deterrent.

So the escalation can continue until our economies—or computers—crumble. The volatility of nations under economic stress, as demonstrated by Argentina in the Falklands, should discourage any plan to drag down the Soviets in an economic race.

But even more crucial is the possibility of computer error. The warning time available to make the decision to use-or-lose missiles is now down to about six minutes; that doesn't leave much time to check the chips.

The threat of "nuclear winter," which the Pentagon now acknowledges, should show that further work on nuclear war-fighting is superfluous. If we (or they) explode even a portion of our present arsenals in a completely "successful" first strike, the aggressor would be committing suicide, cut off from the sun by ash from the fires it started half a world away.

Maybe most important, aside from the actual use of nuclear weapons, what is the cost to society of having so many people involved in building toward destruction? How can we ask our children to care about and for our world when we are busy wiring it for demolition?

If you feel that the budget priorities are wrong, you are the ones in the best position to change them. Groups such as the Mid-Peninsula Conversion Project, Jobs With Peace, Beyond War, High-Technology Professionals for Peace, and the Union of Concerned Scientists are just some of those available to help. An unprecedented number of institutions stand to profit from the arms race. It is up to you to decide whether the profit for the Institution is worth the possible cost to mankind.

And it is up to you to decide whether your contribution to science is overwhelmed by your contribution to the arms race; for who is better qualified? My hope is that you will scrutinize your work in light of your own moral and ethical obligations and act. You are not alone and you can make a difference. If I have falsely inferred that WHOI is becoming too involved in the arms race, I apologize and hope you will strive to keep it that way. If there is reason for concern, I hope you will do everything you can to steer your institution toward its great constructive potential.

David B. Keith
Buzzards Bay, MA

EDITOR's NOTE: Mr. Keith was until recently co-coordinator of Action for Nuclear Disarmament: Falmouth. The views expressed in this letter are his own, and not necessarily those of AND:F.

To the Editor:

For a second time, I feel impelled to express appreciation for *Oceanus* (Vol. 28, No. 1) and its quality and readability.

I particularly appreciated the Watters article on "Terminology." It gives a remarkable view which leads to a better understanding of the problems of inter-disciplinary communication in a growing field. The layman may read and marvel that it can be said *in English!* And it could be equally helpful in other scientific and sociological fields.

Who says a magazine could not possibly be worth $5.00 (or $4.75)?

Richard S. Shuman,
Jamaica Plain, MA

book reviews

Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts, John D. Davis and Daniel Merriman, eds. 1984 Lecture Notes on Coastal and Estuarine Studies No. 11, Springer-Verlag, New York, N.Y. 289 pp. $22.00.

This volume consists of scientific papers emanating from environmental impact studies surrounding the Pilgrim Nuclear Power Station on the coast of Massachusetts, near Plymouth. Most of the studies were done in the decade from 1970 to 1980. The book realizes an objective of one of its contributors (a program manager employed by Boston Edison Company), Robert D. Anderson: to publish power plant environmental impact studies in the open literature. With the exception of the late Daniel Merriman (professor of biology emeritus at Yale University), the authors are associated almost exclusively with private consulting companies or with the Commonwealth of Massachusetts Division of Marine Fisheries.

Although the title includes the words "ecology" and "biology," perhaps "living marine resources" would be more applicable. The papers frequently are arranged in sequences starting with general biology and leading to economic activity. For example, contributed papers treat the seaweeds in general and then treat Irish moss (*Chondrus*) harvesting; lobster larvae, growth and migration of adults, and then commercial harvesting; ichthyoplankton, fishes in general, and then the recreational (but not commercial) fishery.

The book departs from the usual academic approach in that contributors address a wider range of disciplines. Robert Lawton of the Division of Marine Fisheries wrote or co-authored 40 percent of this volume; the topics he wrote on include Irish moss harvesting, lobster biology and catch, fish biology and catch, and biogeography. Richard Toner, of Marine Research, Inc., contributed papers on both phytoplankton and zooplankton. As with other multi-author volumes, it is not clear to what extent each paper received review within the academic research community. Eminently qualified as the editors are, the range of topics in this book probably exceeds their professional expertise. Although some of the authors have been known to this writer for more than 15 years as competent biologists in the private sector, in general it is hard to assess the depth of contributors' experience from their affiliations or articles alone: only 13 citations are listed by authors to their own work, of which just 3 are in the refereed literature.

Letter Writers

The editor welcomes letters that comment on articles in this issue or that discuss other matters of importance to the marine community.

Early responses to articles have the best chance of being published. Please be concise and have your letter double-spaced for easier reading and editing.

The studies reported in about half of the papers involved preparation of species rosters and various indices—such as "species richness," the Shannon-Weaver information index, and the percentage similarity index—which were examined for change over several years' time. Several of the studies also determined semi-quantitative measures of biomass or catch-per-unit-effort and compared these variables over time. The objective, to assess the impact of power plant operation, was made more difficult by regional variability, temporal trends in the data, or by unexplained variability within the sampling matrix. These kinds of observations are not uncommon in biological field studies. Merriman appears comfortable in his conclusion, ". . . no major pernicious alterations in the Cape Cod Bay ecosystem appear to have resulted from the construction and operation of the Pilgrim Nuclear Power Station to date. . . ."

The book begins with a summary chapter by editor John Davis (Technical Advisory Services) dealing with the hydrography, geology, ecology, and meteorology of Cape Cod Bay. Somewhere Davis should have mentioned the extensive bibliography on the subject by Anne Yentsch and others (*Marine and Estuarine Environments, Organisms and Geology of the Cape Cod Region: An Indexed Bibliography 1665–1965*, Leyden Press, 1965), and I was surprised not to find reference to the extensive benthic studies by Melborne Carriker's group at the former Systematics Ecology Program at Woods Hole. Also, since the studies included in this book are on the impact of the power plant's operation on flora and fauna, it would have been appropriate to include a chapter summarizing characteristics of plant operation, such as dimensions of the thermal plume, chlorination and other operational features. Appendix II to the book indicates that these and other studies (such as on aquaculture of salmon and lobster) were conducted, but for some reason they were not discussed in the book. The concluding chapter discusses the kinds of impacts environmentalists tend to focus on, such as fish impingement on intake screens, gas-saturation mortality, and near-field discharge canal effects.

The authors and editors should be commended for production of this work, which reports on efforts of 101 people during more than a decade. For those who question the validity of environmental impact studies performed by the electrical industry, these results are available for scrutiny. Equally important, immediately upon its completion this book becomes a valuable reference for future and ongoing work, such as the dredge disposal site studies currently underway in Cape Cod Bay by the Massachusetts Division of Waterways. This book was one of the last works of Daniel Merriman, who died a year ago. Merriman in his latter years lent his prestige, energy, and skill to power-plant impact studies and, characteristic of the scholar he was, one of his last deeds was to share the information with the rest of the world.

Arthur G. Gaines, Jr.,
Sea Grant Program,
Woods Hole Oceanographic Institution

***Wings in the Sea* by Lois King Winn and Howard E. Winn. 1985. Published for University of Rhode Island by University Press of New England. Hanover, N. H. 151 pp. $15.95.**

In recent years, a growing public interest in whales has spawned many books on these sea giants. Unfortunately, these works often give brief, generalized information concerning numerous species. *Wings in the Sea* is refreshing, therefore, in its focus on only one species, the humpback whale.

The book discusses different aspects of humpback biology, including distribution, migration, feeding, behavior, and reproduction. The chapter on food and feeding is especially informative, with striking black and white photographs portraying various feeding methods and strategies. Researchers do not fully understand some of these strategies, but it does seem that the humpback chooses the most efficient method for catching available prey. The book quotes observations of feeding humpbacks made by several early naturalists, including J. G. Millais, an artist who described and illustrated feeding whales in 1906, after going to sea on North Atlantic whaling vessels.

In chapters on reproduction and underwater sound, before stating their own scientifically-based opinions, the authors present the folklore and common misbeliefs associated with humpbacks. Some of the lore is interesting, but there is danger of confusing fact with fiction, and the reader must take care in making the distinction.

As the Winns state, they began studying humpbacks in 1969. By relating some of their research experiences and difficulties in the field—such as dependency on suitable weather, boat and personnel logistics, the necessity of obtaining international permits, and the unpredictability of sighting whales—the authors impart a truthful view of the often painfully slow progress in whale research.

The last two chapters discuss man's effects on humpbacks, both through whaling and through altering the marine environment. The chapter on whaling spans many years and regions in a few pages, but correctly points out that the humpback occupies a unique niche in whaling history as a result of its behavior and distribution. This is true of each whale species, but the distinctions are often lost in books of a more generalized nature. The chapter on the marine environment details the humpbacks' potential vulnerability to disturbance of their breeding and calving waters, and describes some of the environmental dangers posed to all marine life.

The bibliography of *Wings in the Sea* is extensive for the book's size. Although some citations refer to abstracts or talks given at conferences, many of the other references are obtainable by the interested reader. This book thus seems well-suited to the inquiring whale-watcher or amateur naturalist, offering better information about humpback whales than is available in much of the popular literature, and providing entertaining anecdotes and illustrations that enhance the reading.

Karen E. Moore,
Senior Research Assistant,
Biology Department,
Woods Hole Oceanographic Institution

Dutton's Navigation and Piloting **by Elbert S. Maloney. 14th Edition, 1985. Naval Institute Press, Annapolis, Md. 588 pp. $32.95.**

Many of the abundant navigation books available today promise short or simple routes to mastery of the subject. *Dutton's Navigation and Piloting* makes no such claim; as its title implies, it is a thorough treatment of all aspects of navigation, both inshore and at sea. Since its first publication in the twenties, *Dutton's* has served as the standard text for the U.S. Navy. It incorporates a considerable amount of information specific to naval vessels. Fundamentally, though, it is a painstakingly detailed treatment of all essential aspects of navigation, from the magnetic compass through celestial observations to the use of inertial and doppler sonar systems.

The new, 14th edition and its predecessor (released in 1978) are very nearly identical in content; the major change is the new edition's format and layout. *Dutton's* has adopted an $8\frac{1}{2}$-by-11-inch page, with double columns of text. This saves some 300 pages, allows for larger illustrations, and perhaps makes the book somewhat easier to use. Chapters are subdivided into numbered and titled "articles" and illustrations are numbered to correspond with the applicable article—a very useful feature when using the book as a reference. I do miss the earlier edition's practice of offsetting the article titles in the margin, which facilitated finding the desired segment. The new edition's illustrations are good, though sometimes overly complex. In the chapters on celestial navigation, the illustrations are especially clear—an essential ingredient for understanding this often baffling subject.

Dutton's is extremely thorough on the subject of piloting, or inshore navigation. There is exhaustive treatment of all the basics: soundings, bearings, dead reckoning, running fixes, etcetera. Especially good is the chapter on navigating currents. The major drawback is the naval point of view—not even the merchant fleet can afford a five-man "piloting team" on the bridge. For the recreational boater or small commercial vessel operator, there is no advice on how to manage with a one- or two-man "team." As well, a considerable amount of attention is given to specialized equipment not likely to be found outside the Navy.

As a textbook of celestial navigation, *Dutton's* has been one of a few classics. It is complete, covering astronomy and theory as well as the mechanics of the process. (Many of the "simplified" celestial navigation books are merely step-by-step guides, with no mention of the principles involved.) However, a price is paid for this thoroughness, and that is readability. Other texts have managed to cover the subject in some depth without wearing down the reader as badly. It would be a challenge for a beginner to teach himself celestial navigation using only *Dutton's*.

About 20 percent of the book deals with the many types of electronic navigation, from the common to the esoteric. Radar, RDF, and loran are discussed extensively, giving the reader a good background in the principles of radionavigation and solid instruction in the use of these tools. Interesting chapters describe the workings of some sophisticated systems that the civilian navigator is unlikely to encounter. Since the products available are changing so rapidly, the text tends to stick to general terms when dealing with newer electronics.

Clearly, *Dutton's* is a highly suitable text for the Navy navigator; any other application will leave portions unused. Small-vessel navigators—whether commercial or pleasure—will find an abundance of irrelevant material. Selective use of the applicable material enables one to use this book as a text for introductory study, but this would be difficult for the self-teaching neophyte. Therefore, *Dutton's* is not a good selection for teaching oneself to navigate. It works very well if there is an instructor and adequate time to study the subject in depth. *Dutton's* is a first-class reference volume for navigators with some experience. And for those who simply enjoy the study of navigation, the chapters on topics such as lifeboat and polar navigation are fascinating. Any navigator past the novice stage probably ought to have a *Dutton's* aboard for reference and polishing his skills; I doubt that it needs to be the lastest edition.

Paul DeOrsay,
Captain,
Sea Education Association,
Woods Hole, Mass.

Books Received

Aquaculture

***Crustacean and Mollusk Aquaculture in the United States,* Jay V. Huner and E. Evan Brown, eds. 1985. AVI Publishing Company, Westport, Conn. 476 pp. + xiv. $59.00.**

The high-priced, glamour species of the seafood industry—crustaceans and molluscs—are increasingly exploited in the wild, and are increasingly expensive. This enhances their attractiveness to investors interested in aquaculture. In this book, 16 contributors delineate the status of U.S. culture of freshwater crawfishes and prawns, and marine penaeid shrimps, homarid lobsters, oysters, clams, mussels, abalones, and miscellaneous other crustaceans. One chapter is on monitoring and controlling water quality; the others each cover a taxon, enumerating important species in the taxon and their basic biology, diseases and parasites, culture techniques, status of the taxon's culture in the U.S., and economics and marketing.

Biology

***Common Seaweeds of China,* C.K. Tseng, ed. 1984. Science Press, Beijing, and Kugler Publications, Berkeley, Calif. 316 pp. + x. $125.00.**

About 1,000 species of marine algae inhabit China's coastal waters, including about 100 of economic value. These algae spread over temperate, subtropical, and tropical zones. In this book, 512 of the species are described, each illustrated with a large, clear color photograph. The text includes descriptions of external morphology, color, texture, habitat, occurrance in China, and geographical distribution. When necessary for identification, internal and reproductive characteristics are given. Uses are outlined for economically valuable species. The book includes a systematic list of species and some notes on ecology and production, and a bibliography.

***Marine Biology of Polar Regions and Effects of Stress on Marine Organisms,* J.S. Gray and M.E. Christansen, eds. 1985. John Wiley & Sons, New York, N.Y. 639 pp. + xix. $49.95.**

Forty-four papers presented at the 18th European Marine Biology Symposium, Oslo, Norway, August, 1983. The first part of the book is on marine biology, with papers on the maturation, adaptative, and reproductive processes of the planktonic and algal communities inhabiting the icy waters. The second part deals with the effects of stress on the growth and fitness of marine organisms. Factors such as changes in water chemistry, the presence of oil and other pollutants, and spectral qualities of the water are considered.

***Fishes of the North-Eastern Atlantic and Mediterranean,* Volume I, P.J.P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielsen, and E. Tortonese, eds. 1984. UNESCO, Paris, France. Volume I (of 3-volume set), 510 pp. U.S.: $63.50 (dist. by Unipub); England: £37.50 (HMSO); France: FF250 (UNESCO).**

The culmination of the enormous task of cataloging 1,250 species of fish present in the waters of the Mediterranean Sea and Northeastern Atlantic Ocean. A line-drawing and map of distribution accompany the half- or full-page description of each species. Fundamentals such as length, color, and physiology are given, as well as less observable facts concerning reproduction, habitat, and food. Complete—including species found only in lagoons and estuaries—and up to date—using the latest taxonomy—this book should be useful to zoologists, biologists, ecologists, and fishery scientists.

***Seawatch: The Seafarer's Guide to Marine Life* by Paul V. Horsman. 1985. Facts on File, New York, N.Y. 256 pp. + xiv. $19.95.**

Written by a sea-going biology instructor for other seafarers—sailors and passengers on tankers, ocean-liners, fishing vessels, ocean-going yachts and small coastal craft. The author describes species commonly seen at sea, from phytoplankton to whales; if a species is not in the text, one should at least be able to identify the group to which it belongs. The introduction explains how to use the text and outlines sea ecology. One chapter covers bioluminescence; most chapters are on the faunal groups found in the oceans: coelenterates, molluscs, crustaceans, urochordates, fish, reptiles, and mammals. Each of these chapters begins with a simple classification of the group and describes each organism individually. Other topics in the book include the *Sargassum* community, marine fouling, and life at the seashore.

***Birds of the Texas Coastal Bend—Abundance and Distribution* by John H. Rappole and Gene W. Blacklock. 1985. Texas A&M University Press, College Station, Tx. 126 pp. + xvi. $19.50.**

This guide summarizes the abundance and distribution of every avian species—nearly 500—recorded for the Texas Coastal Bend region. An inset of color plates illustrates the habitats of the region. The chapters supply detailed habitat information, a bird checklist, a discussion of the conservation needs of the region, and maps of migration patterns. A special chapter lists and gives directions to accessible localities of the major habitat types.

***Mysteries of the Red Sea,* photographed by David Pilosof; text by Lev Fishelson. 1984. Massada, Givatayim, Israel. (Distributed in the U.S.A. by Sheridan House, Dobbs Ferry, N.Y.) 145 pp. $29.95.**

Mostly color plates—photographs of life in the Red Sea. The photographs in this book are done in an artistic manner, intended to give the viewer a sense of being in the Red Sea. Some of the close-up photographs reveal amazing, intricate, lavishly colored patterns in the structure of corals, anemones, and other organisms. The text is fairly brief, but provides adequate explanations of the various organisms' life histories. The topics covered, by chapter, are: corals, other reef builders, living together in the coral community, food and shelter, reef dwellers, fishes on the reef's fringe, benthic organisms, nighttime on the reef, and partnerships (such as symbiosis) between organisms.

***The Living Shores of Southern Africa* by Margo and George Branch. Photography by Anthony Bannister. 1981. (Distributed 1984 in U.S. by Helix, Chicago.) C. Struik Publishers, Cape Town, South Africa. 272 pp. $34.00.**

Two books in one. Part I is on the ecology of various coastal environments: how animals and plants interact and how they adapt to their physical surroundings, including rocky shores, sandy beaches, kelp beds, estuaries, and the open sea. A special chapter is devoted to man's relationship with the sea. Part II is a key to identification of marine life, with chapters on Porifera, Cnidaria, Ctenophora, unsegmented worms, Annelida, Crustacea, Insecta, Aranaea, Pycnogonida, Bryozoa, Brachiopoda, Mollusca, Echinodermata, Ascidiacea, and Algae. Two appendices on animal classification and the regulations on bait and food organisms complete the book. Color photographs of organisms *in vivo*, plates of shells, and numerous black-and-white drawings, photos, and maps illustrate this lovely book.

Environment/Ecology

***Oil in the Sea: Inputs, Fates and Effects.* 1985. National Academy Press, Washington, D.C. 601 pp. + xviii. $39.50.**

An update of the 1975 report, *Petroleum in the Marine Environment*. The chapters, which deal with chemical inputs, analytical methods, fates, and effects, have been expanded from the previous volume, thanks to an extensive effort at determining effects of petroleum on marine organisms in recent years. An appendix of oil-spill case histories completes the bulk of the work; two shorter appendices list abbreviations used and public meeting participants. Each chapter is extensively referenced.

***Living With The California Coast,* Gary Griggs and Lauret Savoy, eds. 1985. Duke University Press, Durham, N.C. 393 pp. + xx. $27.95 (hardcover); $14.95 (paperback).**

This latest volume of the *Living With the Shore* series provides information on coastal processes and engineering concerns, and offers detailed anecdotal histories of the entire California coast. It departs from other volumes in the series in that it lacks detailed scientific analyses of coastal dynamics.

***Antarctic Nutrient Cycles and Food Webs,* W.R. Siegfried, P.R. Condy, and R.M. Laws, eds. 1985. Springer-Verlag, New York, N.Y. 700 pp. + xiv. $59.00.**

The 92 papers in this book are from the Fourth Scientific Committee on Antarctic Research Symposium on Antarctic Biology, held at Wilderness, South Africa, in September 1983. The symposium (as does the book) covered nutrient cycling and food webs in terrestrial, marine, and freshwater ecosystems of Antarctica and Sub-Antarctic regions. Each of the five sections consists of an introductory review paper, followed by the full texts from the papers given at the symposium. The five parts are: marine nutrient cycles; terrestrial and freshwater nutrient cycles; marine food webs; terrestrial food webs; and interactions between marine, freshwater, and terrestrial systems.

***Nuclear Winter: The Human and Environmental Consequences of Nuclear War* by Mark A. Harwell. 1984. Springer-Verlag, New York, N.Y. 179 pp. + xix. $16.95.**

An examination of the world after nuclear war, written by a former nuclear weapons officer of the United States Navy who now leads the agricultural and ecological analyses for the International Council of Scientific Unions' project on the environmental effects of nuclear war. The foreward (contributed by the president of the National Audubon Society) concisely sums the recent history of environmental studies of nuclear war, in the process explaining how this book came about. Harwell uses scenario-and-consequences analyses to elucidate the effects of large-scale nuclear wars—those in which sufficient detonations occur for effects to be widespread. After explaining the Council's rationale for its study, Harwell describes initial conditions (human health effects and the state of physical and biological systems); examines intermediate and long-term consequences from factors such as reduced temperatures, reduced light levels, and societal disruptions; describes projected recovery processes; and summarizes the consequences. Written in easy terms, this quantitative study should be accessible to all readers.

The Gulf of Aqaba: Ecological Micropaleontology **by Zeev Reiss and Lukas Hottinger. 1984. Ecological Studies 50, Springer-Verlag, New York, N.Y. 354 pp. + viii. $69.00.**

The Gulf of Aqaba is an important model area for subtropical, oligotrophic marine environments of oceanic gyre-center character. This book synthesizes the results of an interdisciplinary research program that explored the ecology of Aqaba's planktonic and benthic Foraminifera, Pteropoda, and Coccolithophorida. Life strategies and adaptations, composition and distributions were investigated. After the introduction and overall synopsis, the authors describe the physical characteristics of the Gulf. Five parts follow, on climate and primary production, shell producers in the water column, the sea bottom, benthic Foraminifera, and the paleoceanography of the Gulf.

General

Elements of Dynamic Oceanography **by David Tolmazin. 1985. Allen & Unwin, Boston, Mass. 181 pp. $35.00 (hardcover); $19.95 (paperback).**

"What a scientist feels when uncovering the true behavior of oceanic phenomena in abstract columns of numbers, in long and cumbersome, or sometimes intriguingly simple, mathematical relations, is exhilaration. My objective has been to bring this delightful esthetic pleasure within everyone's reach," says the author about his book. It is intended as a text for undergraduate students, but would be appropriate for anyone who wants to understand ocean dynamics without tackling a lot of equations.

North Atlantic Run: The Royal Canadian Navy and the Battle for the Convoys **by Marc Milner. 1985. Naval Institute Press, Annapolis, Md. 326 pp. + xix. $21.95.**

The story of the Royal Canadian Navy's escort operations during World War II—one of Canada's most important contributions to Allied victory. This book covers the period from 1939 to 1945, focusing on the latter half of 1942, when the RCN fought a series of bitter battles in a mid-Atlantic stretch known as the Black Pit, far from land-based air cover. From a tiny force in 1939, the Canadian Navy underwent a tremendous transformation to 96,000 men by the end of the war—an expansion of 50 to one, compared to the U.S.'s expansion of 20 to one. Reaching acceptable standards of efficiency and performance was a struggle, but Canada and the RCN became dynamic elements in the convoy escorts and the battle against the U-boats. For the uninitiated, this book will open up a whole area of Western naval history, including battles at sea and politics at home.

Remote Sensing

Methods of Satellite Oceanography **by Robert H. Stewart. 1985. University of California Press, London. 360 pp. + vii + 16 color plates. $38.50.**

Satellites monitor almost all of our planet; therefore, advances in oceanography could come quickly, assuming methods are found to collect, interpret, and present the cumulating data. Remote-sensing techniques have developed mostly outside traditional oceanography; in this book, the author explains satellite methods useful to oceanographers. Infrared, radio-frequency, and electromagnetic radiation sources are among the topics discussed. The author describes the instruments used for and theories behind each source, and explains how information on water depth, water temperature, chloroyphyll concentration, sea level, the gravity field, and other parameters can be obtained from remote-sensing. The last chapter describes the satellite systems themselves and summarizes the major U.S. satellite series.

Remote Sensing of Shelf Sea Hydrodynamics, **Jacques C.J. Nihoul, ed. 1984. Elsevier Oceanography Series, 38. Elsevier, New York, N.Y. 354 pp. + xii. $69.25.**

The proceedings of the 15th International Liege Colloquium on Ocean Dynamics. These colloquia, organized annually, address recent problems in physical oceanography. This, the 1983 coloquium, looked at remote sensing; 50 participants contributed 18 papers to the proceedings. Among the contributions are papers on the application of remote sensing to problems in water-color imaging, modeling, the marine environment, currents and temperatures, wave-current interactions, ocean circulation, and much more.

Remote Sensing for the Control of Marine Pollution, **Jean-Marie Massin, ed. 1984. NATO Committee on the Challenges of Modern Society, Volume 6, Plenum Press, New York, N.Y. 466 pp. + xi. $72.50.**

Fourteen countries led by France and the United States began in 1976 a study exploring the possibilities of remote sensing techniques for the detection, surveillance, and monitoring of oil spills at sea. This book presents the findings, with more than 35 papers on national requirements and programs, technical results, the use of satellites for oil-spill detection, and the International Standardized Oil Wake Experiments. At the outset of the volume, a special section of conclusions and recommendations gives a brief history of the study (including nations participating and their representatives) and outlines the requirements for and abilities of an ideal remote-sensing system for the detection of marine pollution.

Satellite Oceanography: An Introduction for Oceanographers and Remote-Sensing Scientists **by I.S. Robinson. 1985. Ellis Horwood Limited, Chichester, England, and John Wiley & Sons, New York, N.Y. 455 pp. $59.95.**

An introductory text for advanced undergraduates and beginning graduate students. This book has two major sections; the first, "Fundamentals," includes chapters on space hardware and data transmission, the possibilities for oceanographic remote sensing, principles of remote sensing at sea, and principles of image processing. Secondly, "Applications" includes eight chapters on applications in specific wavelength ranges, and a review of various sensors' applications to oceanic parameters, such as active microwave sensing of sea-surface roughness and microwave scatterometers. The future of this technology in oceanography is the topic of the final chapter.

- **The Oceans As Waste Space,** Vol. 24:1, Spring 1981—A debate over the appropriateness of ocean disposal.
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Issues not listed here, including those published prior to Spring 1977, are out of print. They are available on microfilm through University Microfilm International, 300 North Zeeb Road, Ann Arbor, MI 48106.

- **The Oceans and National Security,** Vol. 28:2, Summer 1985—The proper role of the U.S. Navy, research and national security, and a discussion of the issues surrounding some specific weapons and regions of the globe. Other articles detail the role of the Coast Guard, and Soviet naval strength.
- **Marine Archaeology,** Vol. 28:1, Spring 1985—Details of a rapidly expanding discipline, with articles on prehistoric man on the continental shelf, Atlantis and catastrophe theory, marine archaeology in Israel, and legal and technical issues.
- **The Exclusive Economic Zone,** Vol. 27:4, Winter 1984/85—An assessment of the options open to the United States in developing its new Exclusive Economic Zone.
- **Deep-Sea Hot Springs and Cold Seeps,** Vol. 27:3, Fall 1984—The biology, geology, and chemistry of hydrothermal vents and sulfide seeps. Other articles on the exploration of vent sites and the funding of oceanographic research.
- **El Niño,** Vol. 27:2, Summer, 1984—A comprehensive exploration of the El Niño phenomenon, the oceanic temperature anomaly blamed for abnormal weather worldwide during 1982 and 1983. Articles cover the ocean/atmosphere connection, positive effects of El Niño, its effects on the Earth's rotation, and much more.
- **Industry and the Oceans,** Vol. 27:1, Spring, 1984—Positive uses of the oceans, including genetic engineering and salmon ranching. Also, an article on marine science in China, and a history of the Naples Zoological Station.
- **Oceanography in China,** Vol. 26:4, Winter 1983/84—Comprehensive overview of the history of marine studies in China, including present U.S.-China collaboration, tectonic evolution, aquaculture, pollution studies, seaweed-distribution analysis, the changing role of the Yangtze River, and the administrative structure of oceanographic programs.
- **Offshore Oil & Gas,** Vol. 26:3, Fall 1983—Historical accounts of exploration methods and techniques, highlighting the development of seismic theory, deep-sea capability, and estimation models. Also covers environmental concerns, domestic energy alternatives, and natural petroleum seeps.
- **Summer Issue,** Vol. 26:2, Summer 1983—Articles cover the effects of carbon dioxide buildup on the oceans, the use of mussels in pollution assessments, a study of warm-core rings, neurobiological research that relies on marine models, the marginal ice zone experiment, career opportunities in oceanography, and concerns about the U.S. Exclusive Economic Zone.
- **Summer Issue,** Vol. 25:2, Summer 1982—How Reagan Administration policies will affect coastal resource management, an acoustic technique for measuring ocean processes, ocean hot springs research, planning aquaculture projects in the Third World, public response to a plan to bury high-level radioactive waste in the seabed, and a toxic marine organism that could prove useful in medical research.
- **Summer Issue,** Vol. 24:2, Summer 1981—The U.S. oceanographic experience in China, ventilation of aquatic plants, seabirds at sea, the origin of petroleum, the Panamanian sea-level canal, oil and gas exploration in the Gulf of Mexico, and the links between oceanography and prehistoric archaeology.
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